ASPIRE™
THE CONCRETE BRIDGE MAGAZINE
SPRING 2009
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40th Street Bridge

Tampa, Florida

I-76 ALLEGHENY RIVER BRIDGE
Near Pittsburgh, Pennsylvania

FORTY FOOT PEDESTRIAN BRIDGE
Towamencin Township, Montgomery County, Pennsylvania

RICHMOND HILL BRIDGE
Conifer, Colorado

MINNESOTA I-35W/HWY 62 CROSSTOWN PROJECT
Crosstown Commons, Minnesota

FULTON ROAD BRIDGE REPLACEMENT
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EDITORIAL

Photo: Ted Lacey Photography.

Stimulus Act and the Benefits of Concrete Bridges

John S. Dick, *Executive Editor*

As *ASPIRE*™ goes to press, the American Recovery and Reinvestment Act of 2009 (also known as the Stimulus Act) has been signed into law. Whether it will accomplish its intended purpose remains to be seen. However, one thing is certain: A great many highway and bridge projects will get underway very soon. Many of these bridges will be constructed with concrete components, for a range of good reasons.

An early assessment indicates some $26.6 billion will be apportioned to the states for "highways and bridges." These funds are in addition to contract authority provided in FY 2009 and FY 2010. The rules are specific concerning percentages of funds that need to be obligated by the agencies within a specified period of time, time frames for start-up and completion of projects, and so forth. But that is beyond the scope of our concern here.

What is important to understand is that the concrete industry is poised to respond to this potential flood of demand. Responsiveness always has been a hallmark of the industry, and it was especially important during recent natural disasters and over the past several years when the supply of construction materials was erratic at best.

The owner agencies have increasingly turned to concrete solutions. In 2008, the Federal Highway Administration (FHWA) reported statistics taken from the 2005 National Bridge Inventory (NBI), the most recent year for which complete data are available. For all new and replaced bridges constructed that year, concrete constituted a 65.5% share based on the area of decks. Based on the numbers of bridges, concrete accounted for 76.2% of bridges built in 2005. This percentage has continued to increase through the years.

There are many reasons for the growth of concrete bridges in the United States. Some of these include:

- Wide-spread use of high performance concrete, which provides increased confidence in exceptional long-term performance.
- Freedom from routine maintenance and its interference with traffic.
- Improved efficiencies in construction methods and in the production of materials, and products—resulting in lower unit costs.
- Confidence concerning supply and relative price stability.
- Exciting solutions that expand the range of applications for concrete.
- Sensitivity to creating sustainable solutions.
- Capability for a wider range of aesthetic expressions.
- The ability to meet ever-increasing demand to construct quickly, with improved quality, to reduce the duration of work-zone interference.

ASPIRE is dedicated to bringing to its readers, a broad spectrum of real solutions that illustrate the benefits achieved with concrete bridges across a wide range of challenges, geographies, and stakeholders. This issue features examples of how concrete can be used for long-span bridges or short-span bridges; highway bridges or pedestrian overpasses; and interstate bridges, urban bridges, or rural bridges.

We hope the stimulus program helps you to produce more bridges in the coming year, and we hope our efforts at *ASPIRE* give you new ideas for how to meet those needs quickly, cost effectively, and in aesthetically pleasing ways.

We value your opinion about how we are succeeding. We invite you to share your impressions and comments about *ASPIRE* magazine with us. You can send an email from www.aspirebridge.org, or even better, fill out the quick survey reached by selecting the "Survey" button at www.aspirebridge.org. It offers multiple-choice and fill-in-the-blank questions. It'll take less than 5 minutes to complete.

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40th Street Bridge, Tampa, Fla.
Photo: PBS&J.

READER RESPONSE

Editors,
Again thank you for the opportunity to contribute to your magazine. The latest issue was terrific.

William Collins, vice president
Simone Collins Inc. Landscape Architecture
Berwyn, Pa.

Editor,
ASPIRE™ is my favorite technical magazine!

Tim Shell
KPFF
Portland, Ore.

Editor,
I am an editor in CH2M HILL's Boise office. I would like to download the PDF of the article on Rainbow Bridge and link to it in our office newsletter. John Hinman, the author, is in our office.

Eric Oden
CH2M HILL
Boise, Idaho

Editors,
I've had a couple people comment to me in the last few days about how much they like ASPIRE. You guys are obviously doing something right.

Fred Gottemoeller, principal
Bridgescape
Columbia, Md.

Editor,
Just wanted to say "Thanks !!" for sending us the copies of the ASPIRE magazine that includes the NH article. It is well presented and formatted, and I was glad to see that the photos were clear and sharp. Thanks for the opportunity of having NH prepare an article for ASPIRE.

Mark W. Richardson,
Administrator, Bridge Design Bureau
NH Department of Transportation
Concord, N.H.

Editor,
"…wanted to let you know we thought the article turned out great ("Custom Arches," ASPIRE, Winter 2009, p.18). Our engineer in particular was pleased. He was especially excited about the Aesthetics Commentary by Frederick Gottemoeller who 'got what we were trying to do.' Mr. Gottemoeller really understood our objectives and expressed them so well."

OBEC Consulting Engineers
Eugene, Ore.

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Dr. Dennis R. Mertz is professor of civil engineering at the University of Delaware. Formerly with Modjeski and Masters Inc. when the *LRFD Specifications* were first written, he has continued to be actively involved in their development.

Craig Finley is founder and managing principal of Finley Engineering Group Inc. (FINLEY), a bridge and construction engineering firm based in Tallahassee, Fla. A two-time winner of the ASBI Leadership Award, Finley has participated on some of the most noted precast segmental projects of the last 25 years.

Frederick Gottemoeller is an engineer and architect, who specializes in the aesthetic aspects of bridges and highways. He is the author of *Bridgescape*, a reference book on aesthetics and was deputy administrator of the Maryland State Highway Administration.

MANAGING TECHNICAL EDITOR

Photo: Ted Lacey Photography

Dr. Henry G. Russell is an engineering consultant, who has been involved with the applications of concrete in bridges for over 35 years and has published many papers on the applications of high performance concrete.

CONCRETE CALENDAR 2009/2010

For links to websites, email addresses, or telephone numbers for these events, go to www.aspirebridge.org.

April 20-21, 2009
2009 ASBI Grouting Certification Training
J.J. Pickle Research Campus
The Commons Center, Austin, Tex.

April 22-26, 2009
PCI Committee Days
Westin Hotel, Chicago, Ill.

May 4-7, 2009
World of Coal Ash (WOCA 2009)
Lexington Convention Center, Lexington, Ky.

May 11-15, 2009
PCI Quality Control & Assurance Schools, Levels I, II & III
Certified Field Auditor and Industry Erection Standards Schools
Sheraton Music City Hotel, Nashville, Tenn.

May 31, 2009
The Fifth International Conference on Bridge Maintenance, Safety and Management
Abstracts due May 31, 2009, for IABMAS2010, to be held July 11-15, 2010
Loews Philadelphia Hotel, Philadelphia, Pa.

June 14-19, 2009
International Bridge Conference
David L. Lawrence Convention Center, Pittsburgh, Pa.

June 15, 2009
fib International Congress (hosted by PCI)
Abstracts due June 15, 2009, for this event, to be held May 29-June 2, 2010
Gaylord National Resort & Convention Center, National Harbor, Md.

July 5-9, 2009
AASHTO Subcommittee on Bridges and Structures Annual Meeting
Hilton Riverside Hotel, New Orleans, La.

September 13-16, 2009
PCI-FHWA National Bridge Conference
Marriott Rivercenter Hotel and Henry B. Gonzales Convention Center, San Antonio, Tex.

September 21-23, 2009
Western Bridge Engineer's Seminar
Sacramento Convention Center and Sheraton Grand Hotel, Sacramento, Calif.

October 25-27, 2009
2009 ASBI 21st Annual Convention
Hilton Hotel, Minneapolis, Minn.

November 8-12, 2009
ACI Fall Convention
Marriott New Orleans, New Orleans, La.

January 10-14, 2010
Transportation Research Board Annual Meeting
Marriott Wardman Park, Omni Shoreham, and Hilton Washington, Washington, D.C.

PBS&J

STANDARDIZING SUCCESS

by Craig A. Shutt

PBS&J creates innovative solutions by focusing on efficiency, constructability, and long life

Many complex, long-span structures receive plaudits for innovative concepts that stretch bridge design and material properties. PBS&J has done its share of such projects, but its designers pride themselves more on their ability to bring innovation to the more conventional structures that are designed every day. And their work to standardize components and extend durability attributes help create more efficient and economical designs that benefit the industry.

"Clients come to us because of our general design philosophy, which is to create safe designs that are constructable," explains Amir Kangari, national transportation structures director in the firm's Tampa, Fla., office. "Probably most important, in this litigious environment today, we aim to create high-quality, error-free construction documents that provide an economical solution that's innovative and holistic to the overall transportation need, not just a bridge that connects two points. We apply this philosophy in all of our bridge designs throughout PBS&J's varied client base, which includes surface-transportation, airports, transit, and pedestrian and wildlife-crossing type projects."

The 40th Street Bridge in Tampa, Fla., features a single post-tensioned concrete span with special aesthetic treatments created by local high-school art students. They learned the basics of conceptual design, and contest winners had their designs' ideas, colors, and shapes incorporated into the formal aesthetic plan.

Adds Joseph McGrew, division manager for national transportation structures in the Atlanta, Ga., office, "One key goal is constructability. We are always looking for opportunities to save money during construction by better understanding the concerns of the contractor who is constructing our design."

That focus has led the firm's designers to specify concrete components most often, he says. "The majority of our designs use concrete, with a mix of both cast-in-place and precast concrete designs." The final design often plays to the region's own strengths, notes Ram Kozhikote, group manager of structures in the Orlando, Fla., office. "It depends on the availability of precast concrete plants in the area and what contractors are most familiar with," he explains. In the East and South, precast concrete designs predominate, whereas West Coast designs often feature cast-in-place concrete. "We are working with the precast industry in many regions to revamp I-girder shapes to be more efficient and competitive."

"Concrete's flexibility allows us to do things we couldn't do with steel structures," agrees Glenn Myers, principal technical professional in the Fort Lauderdale, Fla., office. "We can cast any shape needed, which gives us the ability to overcome many challenges."

An example can be seen in the design for the north taxiway at the Cincinnati/Northern Kentucky International Airport in Erlanger, Ky. The single-span, 214-ft wide cast-in-place concrete bridge allows planes weighing up to 1.6 million pounds to traverse its length, spanning an existing two-lane service road that ultimately will widen to four lanes. The bridge required a shallow profile due to the existing roadway beneath.

During the planning phase, designers suggested a shallow voided-slab concrete deck superstructure post-tensioned in both longitudinal and transverse directions. "This design addressed several issues, including construction efficiency and low, long-term maintenance needs," says Kangari. "We created a longer, more open span with no intermediate pier, so it doesn't box in the client for future expansion."

'One key goal is constructability.'

The design for the new taxiway at the Cincinnati/Northern Kentucky International Airport features a cast-in-place voided-slab concrete deck superstructure with a 4.5-ft structural depth to maximize clearance for an existing underpass. Post-tensioning eliminated the need for an intermediate pier, allowing future expansion of the road.

Such spans show concrete's flexibility and are becoming more common, the designers note. "Concrete is a much easier material with which to design unusual shapes than other materials," says McGrew. Kozhikote agrees. "Many of our bridge projects are in the mid-length span range, and the concrete designs compete very effectively with steel. And now segmental precast concrete girders are helping to eliminate any disadvantage for longer spans as well."

PBS&J's work for the State Highway 45 Interchange project in Austin, Tex., features full program-management services on the diamond interchange consisting of 10 major bridges and structural designs for several high-level structures, and a double-deck structure with on/off ramps. Precast concrete beams were used for all of the bridges' superstructures. Photos: PBS&J.

New Standards Coming

To encourage that competition, PBS&J and others in the precast industry are working with the central office of the Florida Department of Transportation to implement new standards for prestressed concrete beams, with the goal of extending their span range to 200 ft. The designs will take their cue from girders being used in other states, Myers notes. "New shapes and higher concrete strengths are allowing us to look at concrete for more efficient designs," he says. "This work will create a more competitive alternative and open new design options."

'New shapes and higher concrete strengths are allowing us to look at concrete for more efficient designs.'

But while PBS&J creates its share of long-span designs, it shines brightest on its work with midrange, conventional designs. Bringing their innovative concepts to these designs creates great challenges, says Kangari. "All of our clients are looking for innovative ideas, and to create innovative designs that help achieve their goals within a conventional design is our greatest challenge."

Long-span, complex bridges offer greater freedom to create innovative designs, he notes, because they're expected in that context. "But to convince bridge owners to use new concepts for designs that are done day in and day out provides a much greater challenge, because of the expected boundaries. It forces us to use all of our creativity in the concept-study and preliminary-engineering phases. Those portions have become pretty robust as we engage the client with our ideas for achieving the goals in the most efficient manner."

An example can be seen in PBS&J's work on the State Highway 45 Interchange in Austin, Tex. The firm provided full program-management services over a 10-year period for the 16.7-mile-long roadway improvement project involving 10 major bridges. In addition, PBS&J provided structural designs for a portion of the project including a double-deck structure using precast concrete Type IV AASHTO girders with simple spans and conventionally reinforced concrete straddle bents.

The straddle bents' unique shape, requested for aesthetic reasons, was effectively utilized to create a more efficient structural design. Piers received a special aesthetic treatment, including ashlar stone patterns. "It was a simple design, which had many aesthetic features and the creative touches that helped its efficiency," says McGrew.

'We focus on finding ways to increase repetition in our designs to save cost.'

Keys to Constructability

Innovations with conventional designs typically focus on issues of constructability, economics, and maintenance, Kangari notes. Those are the key topics that arise with every project.

Constructability issues play to concrete's strengths, the designers note. Not only do the designers work with local contractors and precasters to ensure each company's strengths are maximized, but they take full advantage of concrete's capabilities for replicating components cost-effectively. "We focus on finding ways to increase repetition in our designs to save cost," McGrew explains. "Carefully selecting standard sections early in the design can save a great deal of fabrication time and cost for the precaster and forming expense for the contractor."

The efficiencies of that approach were shown with the design for the I-4/Lee Roy Selmon Connector Interchange in Hillsborough County, Fla. The multi-level $450-million complex project, one of the largest ever in the area, features both steel and segmental-concrete options. The segmental option consists of both span-by-span and balanced cantilever construction methods. The segmental boxes benefit from the creative use of external post-tensioning, which allows a reduction in the principal stresses, shear reinforcement, and web thickness. Utilizing this creative approach, the PBS&J segmental design experts substantially reduced the estimated cost of the concrete option.

"By standardizing sections in both types of construction and using similar cross-sections, we reduced costs substantially," McGrew says. Standardization also resulted in the capability to use typical pier widths, allowing a great deal of repetition for piers, which added to the savings. Designers also selected one size of drilled shafts, standard footing dimensions, and elastomeric bearings for all span-by-span construction. "Standardization resulted in tremendous savings.

Economic issues permeate the design process, Kangari notes, taking in not only efficiency of component design but also speed of construction to lessen user costs and durability issues to extend the bridge's service life. "Our designs today must help clients in more than one way," he says. "They must solve greater and more long-term transportation problems, such as traffic issues during construction and maintenance needs."

Lessening traffic disruptions during construction has become a key concern, he notes. "Officials are more aware of the costs associated with those disruptions and the need to reduce them," says Kangari. That has led to the expansion of Accelerated Bridge Construction (ABC) concepts, adds Kozhikote. These techniques include building the bridge at a nearby location and then moving it into place, requiring only a brief road closure. Girder launchers and modular designs offer more options. "The less mobilization you need at the site, the more reduction in cost, time, safety needs and disruption to users. The public is demanding faster construction."

Longer Service Life Needed

Maintenance needs have become a key issue as demands are being placed to create 100-year service lives and find ways to reduce the long-term costs required to maintain bridges. "A 100-year service life is becoming more popular because clients

The I-4/Lee Roy Selmon Crosstown Connector in Tampa, Fla., will create a new interchange between the two freeways. Six PBS&J bridge design teams from different offices are providing the design work, which will feature both steel and concrete options. The concrete option will utilize a combination of segmental construction and cantilevered post-tensioned spliced concrete beams. Standardized components throughout the project will greatly reduce costs. The project is expected to be let for construction in summer 2009 and take up to 5 years to complete.

The U.S. 17A/SC 41 Bridge over the Santee River in Georgetown, S.C., sits downstream of Wilson Dam and the St. Stephens Power House, making it subject to frequent flooding. The 1.5-mile-long precast concrete bridge was designed for construction in either wet or dry conditions and meets seismic performance "B" category requirements. Photo: PBS&J.

are very concerned about their structures' life spans, and they know such durability is available," says McGrew. "Concrete has an incredible advantage in that area." New admixtures are improving quality and durability, adds Kozhikote, especially for bridges in aggressive environments such as coastal areas.

Myers serves as project coordinator for the R19A project of the Strategic Highway Research Program conducted by the National Academy of Sciences. The project is examining bridge components and systems to find ways to make them last more than 100 years. Concrete work focuses on overcoming corrosion concerns. "We're very early in evaluating options and concepts, but we absolutely are at the forefront of finding ways to extend durability. It appears that funding will be available to get projects going, but maintenance funds are still constrained."

'We absolutely are at the forefront of finding ways to extend durability.'

From Four to 4000

PBS&J got its start in late 1959, when Howard M. "Budd" Post, a young resident engineer with the Florida State Road Department, met Bill Graham while visiting a contractor's office. The prominent South Florida dairyman offered Post an engineering position with his fledgling land-development company, Sengra, which was considering converting pastureland into what is now known as Miami Lakes, the first planned "new town" in Florida.

Post recommended hiring an engineering company instead, suggesting the firm that employed two of his best friends, George G. Mooney and Robert P. Schuh, as well as John D. Buckley, one of the top sanitary engineers in the state. When Graham expressed a disinterest in hiring a large firm, Post offhandedly offered to form a company to do the work. To his surprise, the offer was accepted.

The four men quickly established a corporation, with Schuh being the first to put up his money. As a result, Robert P. Schuh & Associates was born on February 29, 1960. In 1970, the firm was renamed Post, Buckley, Schuh & Jernigan Inc. (PBS&J). The firm grew steadily and then took off during in the 1990s when it acquired a series of related companies in architecture, engineering, and environmental fields.

Today, the employee-owned firm has a staff of more than 4,000 in 80 offices across the United States and abroad, offering services in transportation, infrastructure planning, construction management, environmental consulting, urban planning, architecture, and program management. The firm is ranked by *Engineering News-Record* as the 25th largest consulting firm.

In addition, PBS&J is developing new design criteria to identify the minimum reinforcement required in concrete bridge members (NCHRP Project No. 12-80). PBS&J's Dr. Jay Holombo, Dr. Sami Megally, and Morad Ghali are working with Dr. Maher Tadros of the University of Nebraska. Their research could improve constructability and reduce the costs of concrete bridge members.

Indeed, the new administration's stimulus package will provide the impetus for more projects to begin in both design and construction. "We expect we will be seeing more projects being funded in the near future," says McGrew. "And we expect to be involved in finalizing many of the existing designs that are ready but just need approval, with more going into the pipeline. The designs will be across the spectrum, including quite a few large projects."

The need for efficiency will increase the interest in alternative delivery systems, notes Myers. "Design-build options are growing, not only because they provide speed of construction but also because they improve efficiency, which saves money. The design-build approach allows us to work with contractors in ways that are most effective for them based on their capabilities. Doing that provides a better approach and a better price than a typical design can provide. The state DOTs are open to this system, and it plays to our own strengths."

Funding also will be supplemented by external sources, predicts Kangari. "There is growing interest in public/private partnerships, with private money being invested in infrastructure to aid local developments," he says. That can bring more challenges, as it creates more needs and different agendas, and it also puts the focus on durability. "If private companies are providing the long-term maintenance, they are very interested in not only good designs but also low maintenance costs."

PBS&J's designers welcome those challenges as they work to wring more efficiency from every structure they create. "Our clients appreciate practical solutions that meet all of their needs," says Myers. "But when something different or unique is warranted, we find the solution."

For more information on this or other projects, visit www.aspirebridge.org.

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SUSTAINABILITY

by Craig Finley,
Finley Engineering
Group Inc.

Get In, Get Out, and Stay Out

Several years ago, even before sustainable development was the important topic it is today, the American Segmental Bridge Institute (ASBI) acknowledged the following phrase as an organization goal—get in, get out, stay out.

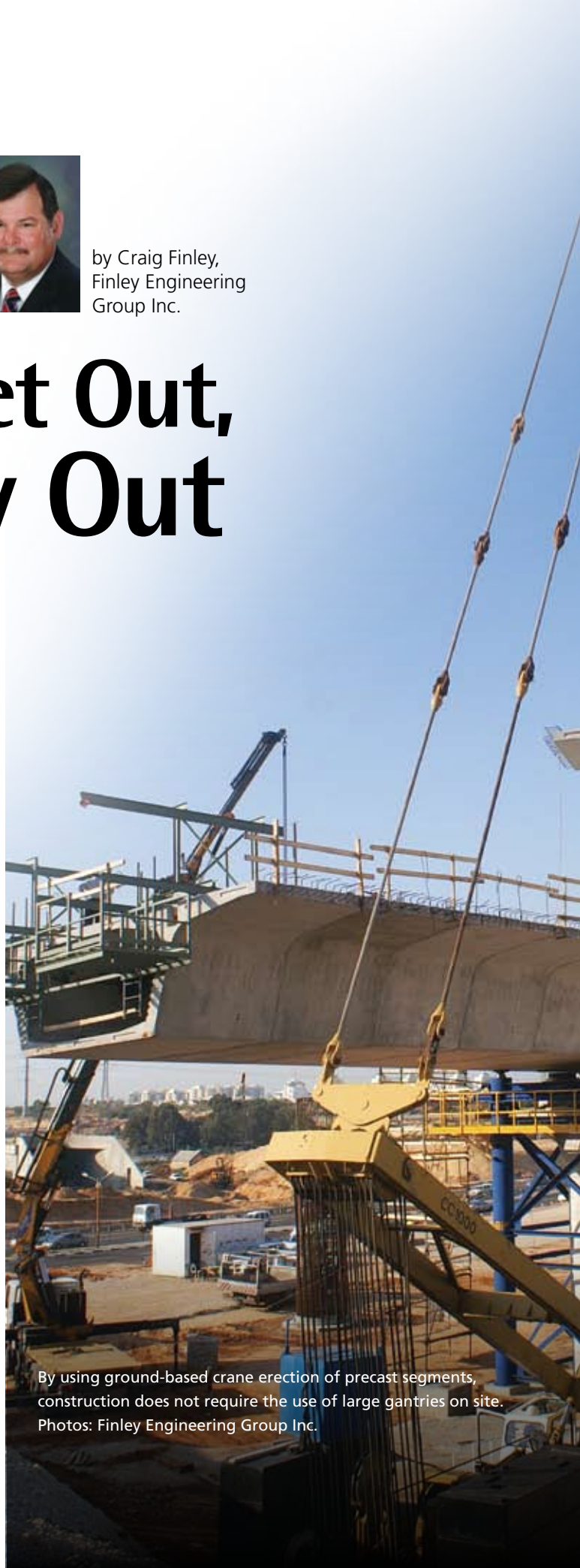
Cliff Freyermuth, who was then ASBI director, wrote in 2003 that this concise statement summed up ASBI's mission of "… reducing project construction time and reducing the need for project maintenance activities following construction."

What does that have to do with sustainability? Plenty, if you consider sustainability more than an issue for environmentalists and ecologists. Sustainable Measures, a consulting firm dedicated to promoting sustainable communities, says sustainability can be measured by whether the "economic, social, and environmental systems that make up the community are providing a healthy, productive, meaningful life for all community residents, present and future."

That's a lot bigger than using energy-saving bulbs in the lighting plan.

At its core, sustainable development offers all kinds of short- and long-term benefits to a community—whether it's the residential community, the driving public, or the environment.

With recent advances made in post-tensioned segmental concrete bridge construction, we're making significant strides toward achieving higher levels of sustainability in our projects as an industry. Specifically, new grouting material specifications and new approaches to grouting tendons, improvements in epoxy technology, innovation in post-tensioning systems, and new developments in concrete mix designs resulting in better, higher-strength concretes are improving our ability to get in, get out, and stay out.



By using ground-based crane erection of precast segments, construction does not require the use of large gantries on site. Photos: Finley Engineering Group Inc.

National grouting standards and a certification program have contributed to improved performance. Photo: American Segmental Bridge Institute.

Grout and Epoxy Improvements

The Florida Department of Transportation (FDOT), in its *Post-Tensioning Tendon Installation and Grouting Manual*, states: "Good corrosion protection of post-tensioning is essential for structural integrity and long-term durability. Over the years, occasional failures have been detected that were attributed to inadequate grouting and lack of overall protection."

Grout originally had two roles in post-tensioned bridge projects—to bond the tendon to the surrounding concrete via corrugated ducts and to fill the duct and prevent corrosion caused by contaminants. However, problems arose related to grouting. With no set standards for uniformity, grouting systems tended to bleed water, incur installation voids, and leak at ducts and deviation pipes. Other issues included lack of cap protection, chemical issues for set and hardening, and duct cracking.

In recent years, the development of national grouting standards and specifications, a grouting certification program, and more intensive training have dramatically improved performance. Now, with virtually no grout issues, bridges require less inspection and maintenance, and they last longer.

Early epoxy was also sometimes problematic, failing to properly cure, not providing the necessary waterproofing to the deck; and variations in thickness of the epoxy affected the segment geometry. As an industry, we learned that a one-size-fits-all approach to epoxy technology would not work, so we developed a variety of different formulations to address project variables such as extreme temperatures and set times.

Unlike the grouting improvements, which were driven by ASBI and the Precast/Prestressed Concrete Institute (PCI) in cooperation with the states, the evolution of epoxy mixes was driven by manufacturers competing to improve a product that as originally introduced, was inadequate.

In both cases, but in different ways, the industry's innovations reinforce the notion that good construction practice, and the sustainability that accompanies it, are evolutionary.

Improvements in post-tensioning techniques are also reaping performance and durability rewards on major bridge projects. These include low-relaxation strand, improved analysis techniques and design software, the use of unbonded tendons in extruded sheathing, encapsulated anchors, diabolos, and development of prepackaged, non-bleed grouts for bonded post-tensioning.

An effort is currently underway to establish a national standard for post-tensioning; just as such standards were achieved for grouts and grouting. Proponents of this standard (including the writer) are reviewing and adapting state codes into a single national standard for post-tensioning, with a goal of 12 to 18 months for implementation.

Longitudinal view of Bridge 22 on Road 431 in Israel, built in precast segmental cantilever construction. Photo: Finley Engineering Group Inc.

Aerial view of the Ein Ha'kore Interchange of Road 431. Precast concrete segmental bridges offer insights into how durability and sustainable construction intertwine. Photo: Danya-Cebus.

Road 431 in Israel

The introduction of external post-tensioning tendons has also helped change the nature of the corrosion protection system, as illustrated by the Road 431 project in Israel.

Time was the most compelling reason to use precast segmental construction with external tendons on the Road 431 Ein Ha'kore Interchange Bridges in Israel. With a very limited design and construction schedule, and several other aspects of the overall roadway project dependent on prompt completion of the interchanges, the project team needed to perform quickly.

Deviation segment featuring post-tensioning tendon diabolos in the foreground. Photo: Finley Engineering Group Inc.

The external post-tensioning system reduced the segment cross-sectional area, including narrower web width and bottom slab thickness. This resulted in lower superstructure weight and foundation loads, and better utilization and effectiveness of the post-tensioning system. With smaller sections, the same post-tensioning force achieved higher compressive stress in the concrete and reduced cracking potential, meaning lower cost and better performance.

Also, external tendons meant that fewer segments required post-tensioning embedments and associated details, so segment casting was faster and more efficient. The system reduced post-tensioning operations in the field as there were fewer tendons to install, less anchorage hardware, and fewer stressing operations. The continuous duct also reduced the number of connections.

When considered collectively, these factors positioned the Road 431 project as a model of sustainability.

Because Road 431 is a build-operate-transfer project, contractor/concessionaire Danya-Cebus was particularly sensitive to durability issues and conscious of inspection and maintenance of the infrastructure. Since it is a toll road, any shutdown for inspection or maintenance would reduce income. So staying out was equally as important as getting in and getting out.

Because external tendons are not encased in concrete, maintenance teams can ensure that all strands remain protected against harmful exposures by simple visual inspection of the tendon ducts. External tendons can be inspected for nearly their entire length and repair teams can repair any defect from inside the box girder. Such defects would include grout voids, split ducts, and tendon damage.

Conclusion

By focusing on getting in, getting out, and staying out, a bridge design and construction team can contribute greatly to sustainability goals. Less construction time usually means fewer traffic problems and, as a result, reduced smog, faster commute times, and an overall improvement in qualify of life. A more durable bridge means less down time for inspection and maintenance, a higher level of safety, and a longer-lasting structure.

In the United States, with billions of dollars from the stimulus bill likely to be spent on bridge construction and reconstruction, and an industry wisely focused on increasing sustainability in all areas, we should continue our quest for innovation and improvement in our construction processes and techniques. This way, our country's investment in bridge infrastructure will be rewarded with highly efficient, rapidly built, and low-maintenance structures that do their job and do it for a long, long time.

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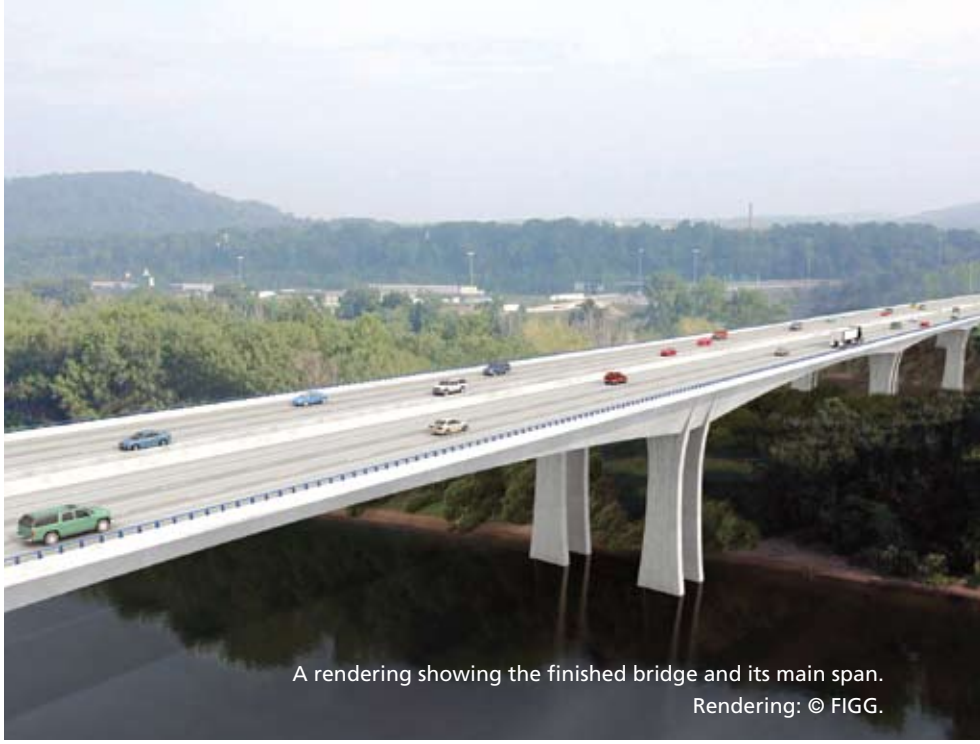
PROJECT

ALLEGHENY RIVER BRIDGE

Sustainable Design and Construction



A rendering showing the finished bridge and its main span.
Rendering: © FIGG.

by Brian Ranck, Pennsylvania Turnpike Commission and Ken Heil, FIGG

New Pennsylvania Turnpike Bridge balances aesthetics, economy, and environmental sensitivity

The Pennsylvania Turnpike Commission's new Allegheny River Bridge, near Pittsburgh, is Pennsylvania's first cast-in-place balanced cantilever bridge. The bridge construction began shortly after the U.S. Open Championship at Oakmont Country Club's golf course in the summer of 2007, and the bridge construction will be completed in early 2010, ahead of the U.S. Women's Open Championship at Oakmont. The Pennsylvania Turnpike bisects Oakmont Country Club within the limits of the Allegheny River Bridge project.

The existing Turnpike Bridge over the Allegheny River was opened in December 1951 and carried two lanes of I-76 traffic in each direction. Options to both replace and repair the aging structure were evaluated prior to design of the new bridge. The narrow width of the existing bridge, projected traffic demands, and the Turnpike Commission's long-term goal of widening to three lanes in each direction led to the decision to replace the existing bridge.

The new bridge carries I-76 over the Allegheny River and consists of twin 2350-ft-long parallel structures for eastbound and westbound traffic with an 8-ft-wide gap between bridges to facilitate future access. The alignment of the new bridge is downstream and roughly parallel to the existing bridge, allowing two lanes of traffic in each direction to be maintained during construction and minimizing traffic impacts to Pennsylvania Turnpike customers. The contract was awarded for the project in May 2007 with a low bid of $189 million. In addition to the main river bridge, the overall Allegheny River Bridge Replacement Project also includes three overpass bridge replacements, reconstruction of the Allegheny Valley Interchange ramps and interchange bridge, construction of three major walls, approximately 2 miles of approach roadway reconstruction, and demolition of the existing bridge.

The New Bridge

Variable depth concrete segmental box girders which are 26 ft deep at the

profile

I-76 ALLEGHENY RIVER BRIDGE / NEAR PITTSBURGH, PENNSYLVANIA

ENGINEER: Figg Bridge Engineers Inc., Tallahassee, Fla.

CONTRACTOR AND POST-TENSIONING CONTRACTOR: Walsh Construction Company, Chicago, Ill.

CONCRETE SUPPLIER: Stone and Company, Tarentum, Pa.

FORM TRAVELERS FOR CAST-IN-PLACE SEGMENTS: NRS-ASIA, Norway

The Pennsylvania Turnpike Commission's new Allegheny River Bridge will result in a sustainable bridge that will serve the Pittsburgh area for many years.

main span piers, 19 ft deep at the side span piers, and 11 ft deep at midspan cross the Allegheny River Valley. Using traveling forms, the bridge is being cast in place using the balanced cantilever method, working from the tops of the piers. Incrementally working out from the piers, five cantilevers result in six spans of 285, 380, 380, 444, 532, and 329 ft. The two end spans include 105-ft- and 69-ft-long portions beyond the balanced cantilever that are cast in place on falsework.

The cross section of the segmental box girder was designed as a single-cell box girder with a constant core form without ribs or transverse drop beams in order to simplify formwork and casting operations. Variable wing lengths accommodate deck widths from 61 ft (typical) to 84 ft at the westbound end span adjacent to the interchange.

Each segment is cast with 2 in. of additional monolithic top slab concrete thickness to form an integral wearing surface. The top flange of the box and the integral wearing surface were post-tensioned in both the longitudinal and transverse directions to provide compression in the deck for long-term durability of the final riding surface. Milling ½ in. at the end of construction ensures the best final riding surface. The design allows for complete removal of the integral wearing surface and replacement with an overlay in the future.

Construction

Balanced cantilever construction began from pier tables cast in place atop twin-wall piers to provide a platform for launching the traveling forms. One side of the pier table was 16 ft long while the other side was 24 ft long; the asymmetry kept the cantilever balanced

A 4-ft closure is all that remains to complete a 380 ft span at a height of 100 ft over the Allegheny River. All photos: © FIGG.

The balanced cantilever construction method allowed traffic flow through the Allegheny River Valley on the roads below while construction took place 54 ft overhead.

CAST-IN-PLACE, POST-TENSIONED BOX GIRDER / PENNSYLVANIA TURNPIKE COMMISSION, OWNER

POST-TENSIONING MATERIALS: Schwager Davis Inc., San Jose, Calif.

PREPACKAGED GROUT: Sika, Lyndhurst, N.J.

BRIDGE DESCRIPTION: Twin, 2350-ft-long, segmental box girder bridges built using cast-in-place balanced cantilevers with a 532-ft-long main span over the Allegheny River

BRIDGE CONSTRUCTION COST: $189 million (total project)

The concrete pier shape was selected by the Pennsylvania Turnpike Commission Team.

to within a half segment to minimize out-of-balance loads on the piers while utilizing constant 16-ft segment lengths for ease of construction.

Year-round cantilever construction utilizes four traveling forms for the superstructure to meet the project schedule. Daily low winter temperatures in nearby Pittsburgh are 20 °F on average, making a cold weather concreting plan vital for maintaining production. Construction began at Pier 1 where access was the most straightforward, with the eastbound (EB) bridge being built first to allow for traffic phasing. Cantilevers 1EB and 2EB were cast in tandem, and then the four traveling forms were alternately advanced to cast the remaining cantilevers. Four-ft-long closure segments connect each of the cantilevers at the center of the span. The superstructure is supported with internal high-strength steel post-tensioning tendons containing nineteen 0.6-in.-diameter strands, and external post-tensioning tendons containing twenty-seven 0.6-in.-diameter strands.

Piers and Foundations

Twin wall piers were selected for an optimum design that eliminated the need for temporary towers during construction. Strength and slenderness of the twin walls are balanced with their height to provide the required flexibility for creep and temperature effects. The piers are 100 ft tall for river Piers 2 through 5 and 60 ft tall at Pier 1. All piers in the river were designed for barge impact loading (3000 kip maximum), ice loading, and scour provisions.

Studies during the design phase of the new Allegheny River Bridge project indicated that several foundation options provided viable solutions. To stimulate a competitive bidding arena and maximize economy in the foundations while taking advantage of contractors' expertise, fully detailed foundation bid options were included in the bid documents for both pipe piles and drilled shafts at all piers. Pier 5, which has relatively shallow bedrock, also had a spread footing option. The contractor chose pipe piles for Pier 1 and drilled shafts for Piers 2 through 5.

As of January 2009, foundation construction is complete, and the twin-wall pier construction is nearly complete, with only Piers 2WB and 5WB remaining. Completion of the eastbound bridge is scheduled for November 2009 to accommodate a key shift of eastbound traffic off of the existing bridge and roadway. Completion of the westbound bridge is scheduled for early 2010.

Brian Ranck is bridge/tunnel maintenance coordinator, Pennsylvania Turnpike Commission, Harrisburg, Pa., and Ken Heil is senior bridge engineer, FIGG, Exton, Pa.

For more information on this or other projects, visit www.aspirebridge.org.

Environmental Challenge


Photo: © FIGG.

A Context–Sensitive Solution

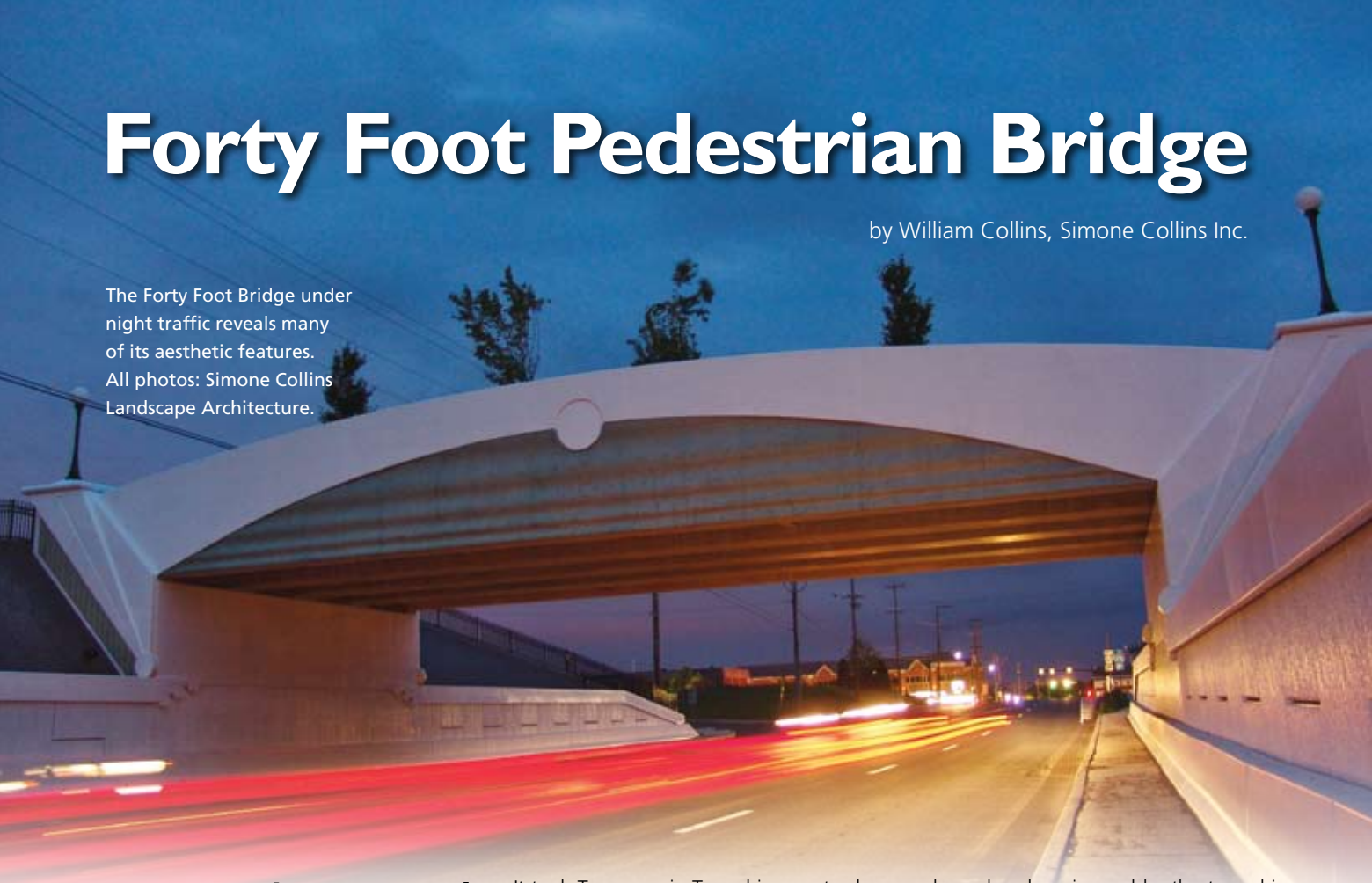
FIGG designed the new Allegheny River Bridge to be a sustainable, environment-friendly structure that would fit in harmony with the landscape around the Allegheny River and Fourteen Mile Island (part of Allegheny Island State Park) while preserving the river and other historically significant areas nearby. Span arrangements were planned to accommodate a busy multi-modal transportation network that runs through the Allegheny River Valley. The new bridge crosses a local road, Norfolk Southern Railroad, the two channels of the Allegheny River, Fourteen Mile Island, and Allegheny Valley Railroad. Balanced cantilever construction allows for continual flow of highway, rail, and barge traffic throughout the duration of construction. The 532-ft-long main span preserves the existing horizontal clearance needed for the navigation channel of the Allegheny River, which supports commercial barge traffic. The new river piers are close to the river banks and island to entirely avoid the archaeologically sensitive zone on Fourteen Mile Island, while being sensitive to the aquatic habitat. The Allegheny River's history of fluctuating water levels also contributed to the decision for locating piers adjacent to the river banks.

The concrete pier shape was selected by the Pennsylvania Turnpike Commission (PTC) Team during the design process using a FIGG Bridge Design Charette™. The PTC was presented with several pier shape options and selected a curved pier that complements the graceful sweep of the variable depth superstructure. FIGG considered constructability, repetition, and reuse of formwork at all piers during design to maintain an economical pier shape. To simplify construction, a parabolic curve was approximated by combining two circular radii. A variable height rectangular base compensates for the different heights at each pier. Concrete formliners and earth-toned stain are used to create a stone texture on the pier faces. The stone texture was selected by the PTC to complement existing stonework at Oakmont Country Club and the surrounding landscape.

The Pennsylvania Turnpike Commission's new Allegheny River Bridge will result in a sustainable bridge that will serve the Pittsburgh area for many years. Built from the top down to keep traffic flowing, the long, sweeping spans deliver an aesthetically pleasing design that also functions to protect the sensitive river environment.

Forty Foot Pedestrian Bridge

by William Collins, Simone Collins Inc.



The Forty Foot Bridge under night traffic reveals many of its aesthetic features. All photos: Simone Collins Landscape Architecture.

Integrating Art and Engineering in Public Infrastructure

It took Towamencin Township over twelve years of planning, design, and construction to depress the alignment of State Route 63 and construct the new Forty Foot Pedestrian Bridge as the context-sensitive signature of an 8100-ft-long highway improvement project. The new 40-ft-wide by 80-ft-long concrete bridge spans the highway known as Forty Foot Road in Montgomery County, Pa. The bridge creates a safe and accessible pedestrian link over the five lanes of traffic that bisect the new Towamencin Town Center.[1]

The Pennsylvania Department of Transportation (PennDOT) served as the construction and funding partner for the transportation improvements that were planned and engineered by the township to integrate smart land-use strategies that included parks, trails, streetscape amenities, structured parking, and incentives for private mixed-use development.

Towmencin Township designed and built a municipal road around the project area as a bypass to maintain state highway and turnpike-bound traffic. This early investment in infrastructure allowed Forty Foot Road to be closed for roadway excavation and bridge construction with reduced traffic maintenance costs, and created a valuable new asset for motorists and local developers. The bridge was built as a turnkey element for Township ownership after completion in 2007.

profile

FORTY FOOT PEDESTRIAN BRIDGE / TOWAMENCIN TOWNSHIP, MONTGOMERY COUNTY, PENNSYLVANIA

FUNDING / CONSTRUCTION PARTNER: Pennsylvania Department of Transportation District 6

STRUCTURAL ENGINEER: QBS International Inc., Pennsauken, N.J.

BRIDGE DESIGNER: Simone Collins Inc. Landscape Architecture, Berwyn, Pa.

CIVIL ENGINEER: McMahon Associates Inc, Fort Washington, Pa.

GEOTECHNICAL ENGINEER: GeoStructures Inc., King of Prussia, Pa.

PRIME CONTRACTOR: RoadCon Inc., West Chester, Pa.

AWARDS: *Award of Excellence, 2008 – Portland Concrete Association (PCA); Project of the Year, 2007 – American Society of Highway Engineers (ASHE) Delaware Valley Chapter (projects over $5 million)*

FAR LEFT: View of pedestrian environment toward south portal showing the concrete deck with cast-in-place planters.

MIDDLE: Exposed aggregate structural deck. Planter wall forms were designed to echo the parapet line and the wingwall rustications.

RIGHT: Structural pylons are clad with architectural wingwall panels, mirrored inside and out. Globe lights were mounted on custom formed pylon caps.

Infrastructure as Community Fabric

From the start, Towamencin Township envisioned the highway project to be an essential part of the revitalized community landscape—in terms of walkability and physical character. When a central pedestrian bridge was selected as the preferred alternative for crossing the highway, the prominent location demanded functions and aesthetics above the ordinary.

Concrete was selected for its economy, durability, and plastic qualities that could deliver a seamless aesthetic in a single structural and artistic material. The sculptural potential of concrete inspired a collaborative process between the bridge designer and structural engineer to incorporate art considerations within the engineering decisions. The result is a practical synthesis of conventional materials and techniques with strategically selected, custom concrete treatments for aesthetics in high–priority elements.

Geometry as an Aesthetic Program Element

The Forty Foot Bridge design consciously features and mitigates specific geometric proportions. The clear span from center to center of bearings is 78 ft 6 in. Fascia beams are engineered as structural members up to 12 ft deep and 90 ft long, with integrally-formed architecture. Beam depths were selected to create parapets to cloister the pedestrian environment from the traffic below. The bridge's width is 40 ft with curving, cast-in-place planters on both sides of the concrete deck to modulate space within the inside faces of the parapets by defining a sweeping, variable-width promenade. Pedestrian lighting was designed for safety and ambiance. The cartway is wide enough to serve as a "civic" space for periodic functions within the town center. The cambered deck serves pedestrian and bicycle traffic only, but is engineered to support an H-20 truck load for maintenance and emergency vehicles.

The sculptural potential of concrete inspired a collaborative process between the bridge designer and structural engineer…

Engineering Innovation – Fascia Beams and Haunched Box Beams

The fascia beams are uninterrupted, full-span, full-height beams that extend above the deck elevation to create the appearance of a rigid frame. They are, however, simple span reinforced concrete beams designed to sit on cast-in-place concrete abutments with standard

PRECAST, PRESTRESSED CONCRETE BOX BEAMS AND CAST-IN-PLACE FASCIA BEAMS WITH INTEGRAL ARCHITECTURE / TOWAMENCIN TOWNSHIP, OWNER

CONCRETE SUPPLIER: Berks Products, Allentown, Pa.

WHITE CEMENT SUPPLIER: Lehigh White Cement, Allentown, Pa.

PRECASTER FOR BOX BEAMS: Schuylkill Products Inc., Cressona, Pa., a PCI-certified producer

PRECASTER FOR MSE WALL AND CAP FINIALS: The Reinforced Earth Company, Vienna, Va.

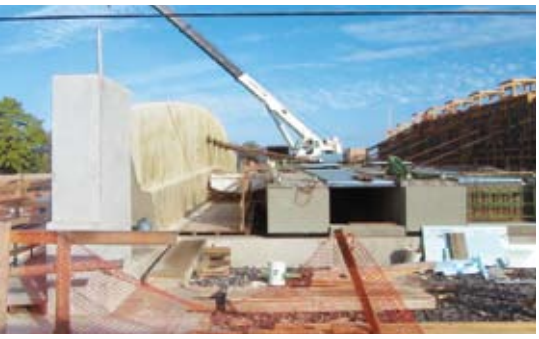
PRECASTER FOR FINIALS AND PYLON CAPS: Architectural Precast Inc., Burlington, Ky.

BRIDGE DESCRIPTION: An 80-ft-clear span by 40-ft-wide pedestrian bridge, exposed aggregate structural deck on conventional spread box beams, and ornamental fascia beams

BRIDGE CONSTRUCTION COST: $1 million for the bridge as part of a $13 million highway reconstruction project

The East fascia beam showing the rippled form, abutments, paver-faced sloped walls, MSE walls with precast cap finials, precast wingwalls, and pylon cap.

More and more modern infrastructure will be needed to relate to increasing numbers of people outside of vehicles and moving at the speed of foot traffic.



A view of portal with box beams, corrugated deck pans, and fascia beam in place. Note the haunch on the fascia beam to support the cast-in-place structural deck.

laminated neoprene bearing pads. Fascia beams were engineered to act as standard load-bearing concrete stringers. They serve as hybrid members with modified geometry that allows the beams to include the safety functions of concrete parapets, the sound-dampening functions of sound walls, and the expansive surfaces for art forms—all within the new concrete beam design. The L-shaped fascia beams vary in depth from 12 ft at midspan to 8 ft 8 in. over the supports and have a thickness that varies from 18 in. to 20 in.

Within each fascia, 15 epoxy-coated No. 7 bars provide the primary flexural reinforcement, and epoxy-coated No. 4 stirrups act as shear reinforcement. The ends of the beams cantilever behind the abutments toward structural pylons where both are clad with precast architectural wingwall panels. The structural concrete deck bears on interior haunches of the fascia beams. This design allows deck edges to be hidden behind the fascia beams, so that the structural deck is only exposed as the wearing surface with aesthetic treatments. Concrete buttresses hidden within the cast-in-place planters tie the fascia beams structurally to the deck.

The concrete deck is also supported by three interior 48-in.-wide by 39-in.-deep precast, prestressed concrete box beams. The beams were haunched 13 in. to simplify the forming and casting of the cambered deck. The beams varied in depth from 39 in. at the supports to 52 in. at midspan. The interior void form varied in depth as well, maintaining a constant 3-in.-thick top flange and 5½-in.-thick bottom flange.

Art and Architecture

The architecture of Forty Foot Bridge acknowledges typical structural features such as corbels, spring points, camber, hinges, and keystones. Art lines in the concrete are graphic interpretations of forces alive within the bridge, including tension, compression, bearing, and repose.

The Art Deco motif responds to the bold engineering by exploiting the concrete material to form elegant, archetypal arch shapes as shadowed relief, designed to "lighten" the apparent mass of the deceptively large fascia beams. Below the arches, the art of the ripple art forms change frequency to express the fluid nature of movements below a bridge, and functionally create horizontal shadow lines designed to subtly elongate the bridge visually and "de-emphasize" the sense of its vertical dimension.

CAD-generated documents for computer-cut, styrene formliners were used to create molds up to 4 in. deep for the surface topography within the fascia beams. The curved top of the fascia beams was an aesthetic decision accommodated by the engineering to soften the shape, reduce visual "mass," and create the top line of the perceived arch in the fascia beam.

Color for concrete surfaces was specified conservatively to allow for multiple field mock-ups and photo-rendering studies of the actual structure during construction. Color selections were simplified to two colors and bright white. A light green was used below the arch shape to make the rippled surface visually "recede," creating the effect from a distance that it blends with the sky and landscape beyond, making the slender white arch shape over the road appear to leap to the foreground. All finished concrete surfaces were treated with a transparent gloss urethane sealant.

Foundations, Retaining Walls, and Sloped Paver Walls

The substructures are conventional concrete abutments using standard formliners to match the rustications of the adjacent precast mechanically stabilized earth (MSE) retaining walls. Custom-cast finials terminate the lines of standard MSE wall caps at the abutments. Four 85-ft-long MSE retaining walls create the grade separation along the depressed Forty Foot Road.

The sloped paver walls above the MSE retaining walls were designed at a 1:1 gradient to be visible from all directions, and are essential to the success of the design—providing a sense of openness, light, and visual access between the roadway and pedestrian environments. The 45 degree walls also serve to limit the height of the retaining walls to 8 ft, prevent a "tunnel" effect under the bridge, and expose the wingwalls as visible "pylon" elements—all effectively elongating the visual sense of the bridge.

The arches formed in the fascia beams appear to "spring" from the sloped bearing line formed in the pylon panels. Structurally, the sloped walls act as compressive structures to bear against the MSE walls and are tied into grade using the same conventional geogrid reinforcement as the vertical walls. Concrete unit "brick" pavers were laid on a mortar bed in a fan pattern with dark mortar to reduce contrast.

Required roadway clearance below the bridge was achieved by partially depressing the highway and partially elevating the bridge to create subtle 3% approach gradients that allow complete visibility under the bridge to the surrounding town center landscape.

Conclusion

The highway project, including the Forty Foot Bridge, was let by PennDOT under the state contracting process, and the lowest prequalified bidder was selected. The product demonstrates that capable fine craftsmanship is available within the industry to deliver a project with exacting, custom aesthetic specifications.

The success of the fascia beam concept relied completely on engineering innovation to create an extraordinary venue for the proposed artwork, to achieve a rare collaboration where art considerations affect geometry, engineering, and construction methods. The jury for the 2008 PCA Concrete Bridge Awards said Forty Foot Bridge, "…is in itself a work of art." The visual harmony and scale of Forty Foot Bridge succeeds in creating an inviting civic "place" and a landmark for both motorists and pedestrians. The structure features modern engineering design infused with a restrained aesthetic that salutes the inspiration of the historic Merritt Parkway bridges built in the 1930s.

With a pending economic stimulus package and promised rush of infrastructure projects in 2009, we understand that what we build today lives with us for the next half century or more. Enduring infrastructure and quality jobs require smart choices to ensure that our special places are protected and improved by new projects that incorporate the combined talents of engineers, artists, and craftspersons. More and more modern infrastructure will be needed to relate to increasing numbers of people outside of vehicles and moving at the speed of foot traffic. Forty Foot Bridge is an example of a 21st Century project that borrows the best from two previous "eras of infrastructure" by incorporating humanizing art features that gave public works projects of the 1930s depression-era their unique personalities, with typical standardized, mass-produced efficiencies ushered in with the products of the Interstate Highway System of the 1950s.

Reference

1. Collins, William, John Ruff, Kristen York, and Bashar S. Qubain, 2008, "Forty Foot Road Pedestrian Bridge: Integrating Aesthetics and Engineering," Proceedings of the PCI-FHWA National Bridge Conference, October 5-7, Orlando, Fla., 22 pp.

William Collins is vice president, Simone Collins Inc. Landscape Architecture, Berwyn, Pa.

For more information on this or other projects, visit www.aspirebridge.org.

COLORADO CREATES UNIQUE SOLUTION FOR RURAL BRIDGE

by Peter Montoya and Trever Wang, Colorado Department of Transportation

Constant-depth bottom flanges on precast concrete U-girders were converted to a variable depth at the site to reduce fabrication and transportation costs

The Richmond Hill Bridge in Conifer, Colo., creates a separate grade crossing and enhanced safety for nearby mountain residents plus safer access to and from the adjacent fire station. It is part of a larger project to widen U.S. 285 from two to four lanes for approximately 2 miles and create a new animal crossing at the site. Goals for the project included creating a signature design and providing an attractive, cost-efficient structure to inspire later designs along this highway and elsewhere in the state. Achieving these goals required value-engineering the original plan and creating a unique approach in which precast concrete U-girders made with constant-depth bottom flanges were converted into variable-depth flanges at the site.

Initial bids on the widening project as designed by the Colorado Department of Transportation (CDOT) were rejected because they exceeded the allowable maximum bid established by CDOT's cost-estimating engineers. Presented with this challenge to their design, CDOT's designers placed the entire project before an independent value-engineering team to find cost-effective alternatives and reduce the cost.

An initial in-house, value-engineering effort changed the original cast-in-place, variable-depth, parabolic-girder concept to a precast concrete design with constant-depth U-girders and variable-thickness bottom flanges. This allowed the girders to resist large negative moments over the piers. As a result, the owner and engineer could save time and money.

The independent value-engineering team subsequently suggested two minor deletions: eliminating a textured finish

profile

RICHMOND HILL BRIDGE / CONIFER, COLORADO

ENGINEER: Colorado Department of Transportation, Denver, Colo.

CONCRETE PIER CONSULTANT: HDR Inc., Denver, Colo.

PRIME CONTRACTOR: Lawrence Construction Co., Littleton, Colo.

PRECASTER: Plum Creek Structures, Littleton, Colo., a PCI-certified producer

AWARDS: *Best Owner-Designed Bridge, Co-Winner, Precast/Prestressed Concrete Institute's 2008 Design Awards*

The Richmond Hill Bridge in Conifer, Colo., features a striking design that is enhanced by the use of precast concrete components, including trapezoidal U-girders and full-depth deck panels. The V-legs at each end reduce the span length without encroaching on the roadway.

on the girders and a flared-web detail at the post-tensioning anchor plates. But otherwise, they determined that the bridge design, having undergone intensive design reviews previously, was as cost effective as possible. These changes lowered the precast concrete girder costs, but they did not provide the significant overall project-cost reductions required. Subsequently, the team found significant savings in other areas of the project, including modifying roadway geometry and eliminating retaining walls. These changes allowed the project to meet the budget and move forward.

Prior to beginning construction, design engineers created a virtual 3-D model, while the contractor built a full-scale mock-up of the pier leg-to-girder connections. These are both unusual steps for a modest project. Because this project was far from typical, the models provided a better understanding of how the components worked for this signature bridge.

Six prestressed, post-tensioned trapezoidal U-girders, 60 in. deep, were used for the superstructure.

The 215-ft-long bridge features a superstructure composed of all precast concrete components. Six prestressed, post-tensioned trapezoidal U-girders, 60 in. deep, along with 27 prestressed, variable-thickness deck panels were used on the project.

Variable-Depth Flanges Created

Creating the bridge as a precast concrete structure posed a significant challenge, in that the original design featured a parabolic girder with variable-depth bottom flanges to resist the high negative moments over the piers. To accomplish this economically, the precaster took the project's variable-depth bottom flanges and substituted constant-depth precast flanges with the additional thickness provided by cast-in-place concrete hidden inside the girder.

The precaster was allowed to create the constant-depth design as long as horizontal shear reinforcement was provided at the plane between the precast and cast-in-place concrete. However, rather than have shear reinforcement project above the top of the bottom flange, which would have been very difficult due to the steel form at that location, the precaster provided transverse grooves that were form-cast in the interior of the tub. The grooves provided an alternative shear-friction plane. By keeping the bottom flange at a constant depth in the casting yard, fabrication costs and shipping weights were reduced. This was a significant factor, as the girders, with a weight of about 104 tons apiece, were near the handling limits for typical cranes.

215-FT-LONG BRIDGE WITH PRECAST CONCRETE TRAPEZOIDAL U-GIRDERS / COLORADO DEPARTMENT OF TRANSPORTATION, OWNER

BRIDGE DESCRIPTION: Four cast-in-place pier columns, six, 60-in.-deep trapezoidal U-girders, and 27 precast, prestressed concrete, variable-thickness full-width deck panels

BRIDGE CONSTRUCTION COST: $1.354 million ($170.18/ft^2)

Precast concrete deck panels were set over studs on steel plates embedded in the girders.

The V-legs that provide a striking silhouette for the project take their shape and dimensions from the precast concrete U-girders.

In addition, numerous inserts were specified in the webs and top flanges of the U-girders to facilitate the hidden pier cap, the hidden thickened bottom flange, and the end diaphragms at the abutments. Weldable A-706 steel reinforcement was allowed in the girder so that inserts could be positioned in congested areas where there was little or no room for wire ties.

Upon arrival at the site, an additional mat of steel reinforcement was placed at a slope inside the U-girder. Field-placed concrete produced variable-depth bottom flanges that were completely hidden inside the box.

V-Legs Reflect Girders

The V-legs that provide a striking silhouette for the project take their shape and dimensions from the precast concrete U-girders. The width at the top of each pier leg was sized to slightly exceed that of the bottom girder flange. Moreover, the webs in standard precast Colorado U-girders are sloped at a ratio of 4:1 and this slope was allowed to flow into the pier legs, defining the V-shape. As a result, the legs echo the exterior precast concrete girder faces. Sun falling on the piers and on the girders reflects at the same angle, casting shadows of equal intensities on the pier and girders, visually smoothing the transition between these connecting elements.

The aesthetic design produced by the two precast girder lines was superior to that of a single, flat bottom flange that would have been provided in a cast-in-place superstructure. Because the interior cells would have been hidden behind a single flat bottom flange, the cast-in-place approach would have produced a visually undesirable tunnel effect. The transition between each of the two supports at the top of the slant-Vs into two precast concrete girder lines provided a more visually unified appearance than if it consisted of a single bottom flange.

Precast Deck Panels Selected

Full-width precast concrete deck panels were chosen, with a cast-in-place alternative offered as well. The girders were fitted with steel plates embedded in the top flanges. The required numbers of studs were field-welded onto the plates at locations lining up with blockouts in the precast concrete deck panels. Foam board was carefully sized and glued in place along the top flange to contain the concrete used to fill the blockouts and spaces between the tops of the beams and the bottoms of the panels.

The concrete deck panels were delivered from the casting yard, lifted onto the girders, and fitted up. They were adjusted for height with leveling screws and clamps. A concrete mix that was virtually self-consolidating with a spread of approximately 22 in., was used to fill the spaces. This mix exceeded all strength requirements and did not require internal vibration. Using this flowable mix ensured that any congested spaces between the deck panels or within the hidden pier cap were completely filled.

The deck joints were cured under insulated blankets. High-strength post-tensioning rods were inserted into the ducts running longitudinally through the deck. Jacks were positioned, and the rods were tensioned. Finally, all shoring towers (those supporting the girders and the V-legs) were dismantled, leaving a freestanding structure.

To complete the bridge's aesthetics, orange paint highlighted the bridge's face. Painted lines on the exterior webs mimic the angles of the internal strands of the girders.

In addition to the emphasis placed on achieving a high-quality design with innovative thinking, designers also emphasized construction safety. This was also reinforced by the use of precast concrete components, as local precasters have a proven safety record.

The result of this creative thinking by the entire design and construction team was that Colorado received a signature bridge with all visible components sharing elegant proportions, symmetry, unity, openness, and a use of materials that allows for maximum creativity. The work also was completed safely and provided low final costs. It is expected that the bridge will remain durable for a 100-year service life, and initial experience with the finished project indicates that it has more than enough resilience to meet this challenge.

Peter Montoya is a bridge designer and Trever Wang is a bridge engineer and supervisor with the Colorado Department of Transportation, Denver, Colo.

For more information on this or other projects, visit www.aspirebridge.org.

Minnesota Crosstown Project Features

Precast Concrete Segmental Bridges

by Keith Molnau, Minnesota Department of Transportation and Franklin Hines, FIGG

Precast segmental construction offered the most advantages and was the most attractive option

With the casting of this pier segment on October 18, 2007, Minnesota's first precast concrete segmental bridge gets underway. Photo: Mn/DOT.

The Minnesota I-35W/Hwy 62 Crosstown Project features precast concrete segmental bridges utilizing balanced cantilever construction within one of the most highly congested sections of interstate highway system in the region. Approximately 200,000 vehicles per day travel through the project, which is situated in the southern portion of Minneapolis and into Richfield, with the Mall of America and the Minneapolis-St. Paul International Airport nearby.

The old configuration was essentially an at-grade interchange. The traffic from Hwy 62 merged into the left-most (fast) lane of I-35W and caused traffic delays as the traffic wove together. This 1960s design had exceeded its design capacity, had a high accident rate, and was outdated with an aging infrastructure. Additionally, the area has long since undergone densely populated urban sprawl, with homes and businesses built to the edge of the right-of-way along the corridor.

The new layout includes elevated structures that separate the traffic and eliminate the merging and weaving requirements. The use of precast balanced cantilever techniques permits construction in these highly confined areas.

The $288 million contract, the largest in Minnesota's history, includes $99 million for bridges, of which $42 million is the total for the six precast segmental bridges. Construction began in 2007 and is on schedule for the planned 2010 completion date. This project was the first use of precast segmental construction in the state of Minnesota.

Bridge Type Selection

The bridge type selection process for these flyover ramps was based on a combination of several factors.

- The box girder geometry and balanced cantilever construction method offered an approach that better fits the confined work area.

profile

MINNESOTA I-35W/HWY 62 CROSSTOWN PROJECT / CROSSTOWN COMMONS, MINNESOTA

ENGINEERS: *(Each firm designed two segmental bridges)* PB Americas, Minneapolis, Minn. (Lead Designer), URS, Minneapolis, Minn., Parsons Transportation, Minneapolis, Minn.

ENGINEER: *(Project Layout, Staging Plans, and Roadway Plans)* SRF Consulting Group Inc., Plymouth, Minn.

CONSTRUCTION ENGINEERS: McNary Bergeron and Associates, Broomfield, Colo.

OWNER'S REPRESENTATIVE: FIGG Construction Engineering Inspection, Eagan, Minn.

PRIME CONTRACTOR: ALS– A Joint Venture of Ames, Lunda, and Shafer construction companies, Minneapolis, Minn.

SUBCONTRACTOR: High Five Erectors Inc., Shakopee, Minn.

CONCRETE SUPPLIER: Aggregate Industries, Eagan, Minn.

- The segments could be erected during brief night-time or weekend traffic closures.
- With six bridges comprising 461 precast segments, Minnesota Department of Transportation (Mn/DOT) believed the volume was sufficient to overcome the investment for a casting yard and provide an alternative that was more economical than other bridge types.
- Steel girder bridges were considered but deemed less desirable because piers necessitated integral caps that resulted in vertical clearance issues. Integral steel pier caps introduced fracture critical concerns Mn/DOT wanted to avoid. Integral post-tensioned concrete pier caps needed with steel bridges introduced vertical clearance problems due to falsework and the staged traffic lanes. Additionally there were long-term maintenance concerns.

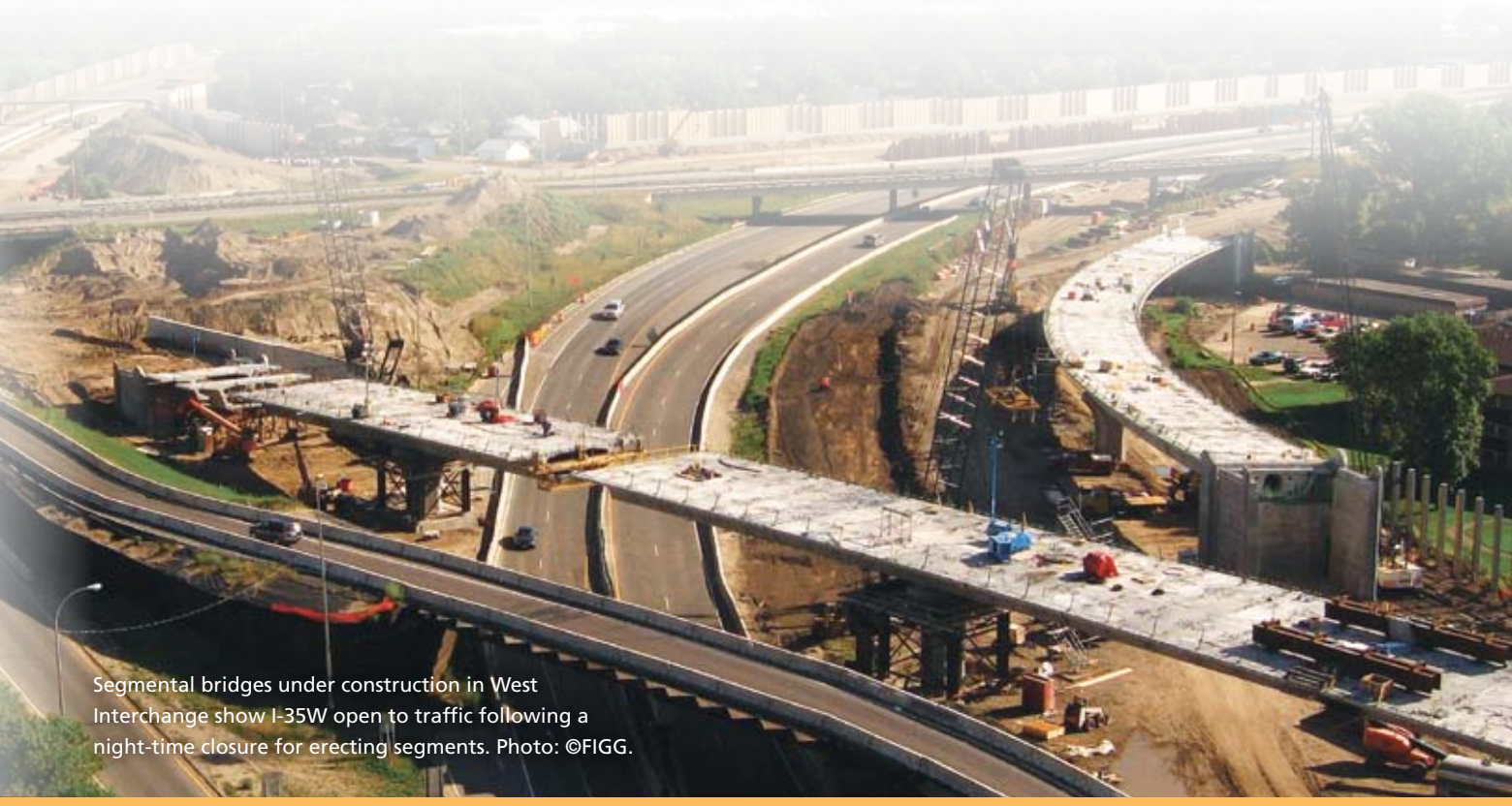
Considering long-term maintenance costs for future painting and deck replacements associated with steel girder-type bridges, precast segmental construction offered the most advantages and was the most attractive option.

Bridge Design Standards and Other Design Considerations

During design, a special effort was made by the lead segmental designers to standardize the precast segmental superstructure components.[1] Initial analysis included verification that one basic precast concrete section would be adequate for the project. In addition to the LRFD design loads, the section would suffice for the special permit truck loading cases required by Mn/DOT.

Therefore, a modified AASHTO/PCI/ASBI Section 8-2 (2400-2) was selected for all six segmental bridges, even though there were three unique roadway widths varying from 33 ft 4 in. to a maximum of 45 ft 4 in. The deck flanges would simply be narrowed or extended as needed to accomplish the bridge width variations. Also, the bottom slab thickness was increased to 24 in. at the pier then tapered to 9 in. thick for the typical precast segments.

More standardization was accomplished following the project letting. The contractor and his segmental specialty engineer wanted to adjust the tendon layouts to eliminate some double layer stacking in both the upper and



Segmental bridges under construction in West Interchange show I-35W open to traffic following a night-time closure for erecting segments. Photo: ©FIGG.

PRECAST, POST-TENSIONED BOX GIRDERS / MINNESOTA DEPARTMENT OF TRANSPORTATION, OWNER

FORMWORK FOR PRECAST SEGMENTS: Southern Forms Inc., Guild, Tenn.

POST-TENSIONING SUPPLIER: VSL, Grand Prairie, Tex. BRIDGE DESCRIPTION:

BRIDGE DESCRIPTION: Six precast concrete segmental bridges with 200-ft-long maximum spans

STRUCTURAL COMPONENTS: 461 precast AASHTO/PCI/ASBI Modified Section 8-2 segments

PRECAST SEGMENTAL BRIDGES COST: $42 Million (six bridges)

The East Interchange near Nicolet Avenue begins to take shape. The two bridges shown come together near a gore area, located off the bridges to allow for clearance of the full-width segments. Photo: © FIGG.

The use of precast balanced cantilever techniques permits construction in these highly confined areas.

lower corners of the box section where the slab thickens near the webs. The proposed changes were acceptable because the stresses in the structures were not significantly affected.

Such changes were reviewed in a streamlined shop drawing review process. In this process, the initial concept approval for a given change was made in advance by the respective designer. Then, final approval was made following a detailed review by the owner's construction engineer, requiring final concurrence from each designer. This streamlined shop drawing review process minimized review cycles and helped avoid delays.

Indoor Casting Facilities

The contractor established a casting yard on property they owned by converting a building into a short-line casting facility. Two sets of forms were used to construct all segments. One set of forms used adjustable form inserts so that it could fabricate pier segments, abutments segments, and typical segments. The second set of forms was non-adjustable and used for production of only typical segments.

Segments are cast, cured, transversely post-tensioned, and stored at the casting yard; approximately 25 miles hauling distance to the project site. Some 6 months after the notice to proceed, the contractor had cast the first segment on October 18, 2007. Casting was completed on January 22, 2009, for all of the project's 461 segments.

During the 2008 construction season, the contractor erected 248 segments, completing three of the smaller bridges in the project's West Interchange and portions of the three larger bridges in the project's East Interchange. The remaining 213 segments will be erected in spring 2009 when weather is favorable. Erection of segments throughout the winter is not practical due to restrictions on the required temperature for grouting operations and minimum temperature requirements for the epoxy in the match-cast joints.

Lessons Learned

Duct Couplers. Recently, post-tensioning suppliers have been urged to develop duct couplers that can be used at the joints of precast segmental bridges. The intent is to provide an additional layer of corrosion protection for the post-tensioning tendons at the match-cast joints. The Crosstown project initially had specified that duct couplers were required based on the Florida DOT's initiative with duct couplers. (See *ASPIRE*™ Winter 2008.)

After the Crosstown project letting, a prototype duct coupler was tested for acceptance. Couplers were cast into mock-up concrete test blocks. The duct with couplers was pressurized with compressed air to test for leakage and maximum sustainable pressure. The assemblage of the duct with the duct couplers was then grouted to also test the installation and grouting procedures and establish a safe upper bound grouting pressure.

When the specimen was cut apart at the joint and examined, the duct coupler was rejected by Mn/DOT based on an excessive void area within the coupler. The concern was that this void would trap water and chlorides that could lead to accelerated deterioration of the tendons and top slab. To resolve the situation, the couplers were eliminated from the contract. It was reasoned that the high-strength epoxy joint at the match-cast face offered adequate long-term durability and corrosion protection. Ultimately, proper attention was focused on match-casting operations so no grouting cross-over (grout leaking at the joints from one duct into another) was experienced during the entire 2008 season.

Segmental bridges under construction in the East Interchange showing traffic on temporary alignments. Photo: Mn/DOT.

Mn/DOT will not likely specify duct couplers on future segmental projects until the couplers from each supplier are fully developed, tested, and preapproved for use. Mn/DOT certainly wants to maximize corrosion protection of the tendons, but not at the expense of potentially reducing the service life of the bridge deck. The decks for these segmental bridges are critical to the longevity of the structures.

Falsework. Precast balanced cantilever segmental bridges are constructed with minimal use of falsework. However, four-legged falsework towers used adjacent to the piers are critical for structural stability during construction. The AASHTO *Guide Design Specifications for Bridge Temporary Works* includes a diagram showing a 1-ft-minimum set-back clear distance behind a barrier for falsework leg placement. This is shown for a tangent section of highway with full shoulder widths. The Crosstown project has curving, nonstandard temporary alignments weaving through the construction area with minimum shoulder widths.

Recent crash studies show that when a truck impacts a barrier, the upper portion of the vehicle extends beyond the barrier into what is termed as the "zone of intrusion." To maintain a safe work-zone, the falsework support legs cannot be allowed to be placed within this zone of intrusion.

The contractor understood the risk and responded to this issue by casting a temporary concrete wall, taller than the "zone of intrusion." Two legs of the tower were then fixed to the top of the wall.

Cold Weather Issues. The segment casting cycle allows a 3-day curing period after which the segment is moved into an outdoor storage area. Concrete test cylinders are kept with the segment during the initial curing period. When the segments are moved outdoors, the cylinders are put on an outdoor curing rack, which happened to be on the north side of the building. These control cylinders then become the basis for determining when the concrete reaches its required strength to erect the segment.

During cold weather, the required 28-day compressive strengths were not achieved on several segments. Prior to erecting these segments in the early spring, the contractor moved them and their corresponding cylinders to a heated enclosure to help increase strength gain. When the initial 28-day strengths were not met, additional cylinders were tested or, as a final step, the segments were cored and the cores tested. All segments eventually attained their required strength. The curing process must be carefully monitored and coordinated with the erection schedule to ensure the proper concrete strength is attained prior to erecting the segments.

Conclusion

Precast segmental bridges are proving to be economical and a good choice for the Minnesota Crosstown project flyover ramps. Being highly elevated structures, they are especially aesthetically pleasing and are expected to provide the added lasting value of low, long-term maintenance costs.

Reference

1. Tse, Joseph K., Paul J. Pilarski, Laura M. Amundson, and Keith Molnau, 2007, "Crosstown Segmental Design Standards," Proceedings of the PCI-FHWA National Bridge Conference, October 22-24, Phoenix, Ariz., 19 pp.

Keith Molnau is bridge design unit leader with the Bridge Office of the Minnesota Department of Transportation, Oakdale, Minn., and Franklin Hines is resident engineer with FIGG, Tallahassee, Fla.

For more information on this or other projects, visit www.aspirebridge.org.

AESTHETICS COMMENTARY

by Frederick Gottemoeller

Economy and elegance have a fruitful convergence in Minnesota's Crosstown Reconstruction. The Minnesota DOT has learned, as New Mexico, Florida, and other states did before them, that concrete segmental construction provides both an economical and attractive solution for flyover ramps in complex interchanges.

Let's start with the economics. In these interchanges the ramp widths can usually be sufficiently standardized to produce long lengths of bridges with similar widths. This means that there will be a large number of similar segments that in turn justifies the establishment of a casting yard. It also allows the standardization of the substructure, resulting in additional economy through the repeated use of a few standard pier forms. Once those economic basics have been met, the inherent advantages of the box girder come into play. The small footprint of the piers compared to a typical multi-column pier bent means there are more places to put the piers, a great advantage in a complex interchange. That, plus the fact that the critical vertical clearance point is often not on the bottom of the girder but on the bottom of the thin overhanging wing, usually eliminates the need for costly and unsightly straddle bents. Finally, balanced cantilever construction minimizes falsework and allows traffic to be maintained with minimal disruption, another savings.

All of these points of economy have their aesthetic payoff as well. First, the box girder, with its wide overhang and deep shadow line, looks thinner than a typical girder bridge of the same depth. The piers occupy a much smaller part of the visual field than typical multi-column pier bents. All piers are essentially the same, varying only in height. They don't have to be modified or rotated from place to place, as multi-column pier bents often do, in order to fit into tight locations. The result is an interchange that is easy to see through and to understand, a great advantage to drivers trying to navigate it. Finally, the girders themselves smoothly and continuously parallel the curves of the ramps. They fit right into the interchange. After all, an interchange is basically an assembly of curves.

OHIO FULTON ROAD BRIDGE REPLACEMENT

by Gregory Kronstain, Ohio Department of Transportation, John Dietrick, Michael Baker Jr. Inc., and Brendan Finn, Cuyahoga County Engineer's Office

OHIO'S CONCRETE BRIDGES

Sitting at the crossroads of a number of the nation's major east-west and north-south transportation corridors, Ohio is second only to Texas in the size of its bridge inventory. Including all state, county, and local bridges 10 ft or more in length, Ohio's inventory includes over 20,000 concrete bridges. Of these, over 7000 bridges, representing some 20 million ft^2 of bridge deck, are prestressed concrete bridges. For the first time, in 2007 the Ohio Department of Transportation built more new concrete bridges than steel bridges. Previous issues of *ASPIRE*™ have featured the Pomeroy-Mason Bridge; Veteran's Glass City Skyway, Toledo; the High-Main Street Bridge, Hamilton; and the Perry Street Bridge, Napoleon. Among the new concrete bridges emerging in the state are a number of creative and innovative structures like the new Fulton Road Bridge in Cleveland.

For over 70 years, the original Fulton Road Bridge stood within Brookside Park and the Cleveland Metroparks Zoo, carrying a significant volume of traffic 100 ft above the zoo, the park, Big Creek, and two active railroad lines. Replacement of this concrete open-spandrel deck arch bridge, which was constructed in 1932, had become imperative because of the severely deteriorated condition of the bridge, which resulted from extensive use of deicing chemicals in northeast Ohio's severe climate.

profile

FULTON ROAD BRIDGE REPLACEMENT / CLEVELAND, OHIO

ENGINEER: Michael Baker Jr. Inc., Cleveland, Ohio

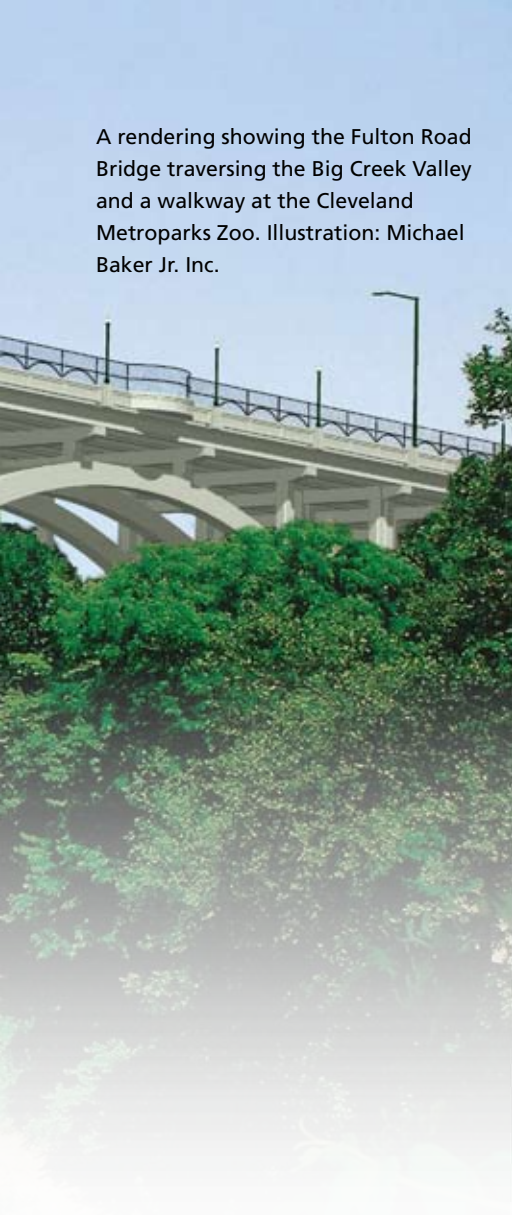
CONSTRUCTION MANAGER: Ohio Department of Transportation

CONTRACTOR: Kokosing Construction Company Inc., Fredericktown, Ohio

CONSTRUCTION ENGINEER: Janssen and Spaans Engineering Inc., Indianapolis, Ind.

POST-TENSIONING SUPPLIER: Dywidag-Systems International USA Inc., Bolingbrook, Ill.

PRECAST ARCH SUPPLIER: Carr Concrete Corporation, Waverly, W.Va., a PCI-certified producer



A rendering showing the Fulton Road Bridge traversing the Big Creek Valley and a walkway at the Cleveland Metroparks Zoo. Illustration: Michael Baker Jr. Inc.

Design considerations represented excellent opportunities for the owner and stakeholders to create a more sustainable, durable, and low-maintenance replacement structure.

With its unique location inside the Cleveland Metroparks Zoo, which is attended by over a million visitors annually, the bridge had long been a highly visible structure and an important symbol to the community. It was also one of the few of its type and era still in use in Ohio. For these reasons, a bridge alternative study was performed to evaluate replacement bridge types, focusing on maintaining the unique aesthetic character and cultural significance of the original structure and minimizing negative impacts to the zoo.

After evaluating a number of conceptual and preliminary bridge replacement types and incorporating public input, a precast concrete arch alternative, with six 210-ft-long spans to resemble the original structure, was selected and advanced to final design. Construction of this unique new structure is currently ongoing with an anticipated completion in late 2009.

Structure Type Selection

The conceptual design phase followed a number of previous efforts to address concerns with the deterioration of the bridge. These concerns are of particular importance in light of the significant pedestrian traffic that passes beneath the structure. The conceptual design effort also encompassed a number of environmental, cultural, and historic issues associated with the replacement of the structure.

Because of the nature of the extensive deterioration in the original structure, rehabilitation was judged to not be a practical alternative. In recognition of the strong sentiment and personal attachment to the original arch bridge by the local populace, it was also decided during development of alternatives that the new bridge be "arch-like" in appearance. Additionally, to limit the impact to the zoo and Brookside Park, and to minimize right-of-way acquisition, it was deemed important to maintain piers at the existing pier locations.

These geometric parameters, established early in the conceptual design, provided a context for the development of bridge replacement alternatives and put practical limitations on feasible replacement types. With the goal in mind of replacing the Fulton Road Bridge with another structure "arch-like" in appearance, the design team initially developed 12 different alternatives for the bridge replacement. Each of these alternatives fit the criteria of being "arch-like" in appearance, even though several were not true arch structures.

The designers worked collaboratively with the Cuyahoga County Engineer's Office (CCEO), City of Cleveland, Ohio Department of Transportation (ODOT), Cleveland Metroparks, the Federal Highway Administration (FHWA), other key stakeholders and the public to systematically evaluate and refine structure type alternatives based on agreed-upon evaluation criteria. Among the criteria judged to be of importance on this project were aesthetics, public input, long-term durability, anticipated maintenance requirements, and construction impact.

The final alternative selected for construction was a precast, post-tensioned concrete arch bridge with 210-ft-long main arch spans similar to the existing structure. This alternative employs the use of modern materials and construction methods with

PRECAST, PRESTRESSED CONCRETE I-GIRDER BRIDGE SUPPORTED ON SIX PRECAST CONCRETE ARCH SPANS / CUYAHOGA COUNTY, OHIO, OWNER

PRECAST BEAM SUPPLIER: Prestressed Services Industries LLC, Grove City, Ohio, a PCI-certified producer

BRIDGE DESCRIPTION: 35-span continuous, 1583-ft-long bridge with AASHTO Type III girders supported on five approach spans and six 210-ft-long precast concrete, post-tensioned arch spans with cast-in-place concrete piers, spandrel columns, and transverse cap beams

COST: $45.9 million; Structure Cost: $293/ft^2

All photos: Ohio Department of Transportation.

In consideration of the desire to maintain operations in the zoo at all times, it was proposed to use precast arch rib segments.

four spandrel columns in each span, giving a more open and contemporary appearance than the original bridge.

The arch ribs of the original structure were cast in place, which necessitated extensive formwork supported from the ground. For the new structure, in consideration of the desire to maintain operations in the zoo at all times, it was proposed to use precast arch rib segments fabricated in approximately 60-ft-long, 70-ton pieces. A top-down approach to the arch construction was proposed to minimize the negative impact to the railroads and allow for continuous operation of the zoo during construction.

The introduction of post-tensioning in the precast arch ribs also represented an opportunity to enhance the long-term durability of the structure. Along with the ability to provide a structure with no expansion joints between abutments, as described below, these design considerations represented excellent opportunities for the owner and stakeholders to create a more sustainable, durable, and low-maintenance replacement structure.

Bridge Design

Right-of-way easements existed for the existing bridge footings only, with the bridge superstructure occupying an aerial easement. Most of the remaining land beneath the bridge is owned by the Cleveland Metroparks Zoo, Brookside Reservation, and the Norfolk Southern and CSX railroads. Thus, the main arch spans were designed to match the original six 210-ft-long arch spans.

The arch spans have a parabolic profile and a 41 ft 8 in. rise. They consist of three precast concrete sections, comprised of two identical end segments and one crown segment. The tall piers supporting the arches lead to greater arch design moments than if the arches were founded directly on rock. These increased moments are resisted using post-tensioning. The individual segments contain two post-tensioning tendons to resist eccentric design moments and the completed arch span is connected with four concentric post-tensioning tendons. While design of the segmental concrete arches included analysis tools that evaluate staged construction and time-dependent creep and shrinkage forces, important design aspects were gleaned from historical design references, including Conde McCullough, the great American designer of many continuous concrete deck arch bridges.

The original bridge had expansion joints between each arch span and drainage conduits located inside the pier columns. Years of deicing salts caused significant deterioration of the structural concrete, contributing to the bridge's demise. The CCEO desired a low maintenance, durable structure for economic considerations and to minimize future impact to the zoo. Additionally, the owners desired a superstructure that would facilitate part-width deck replacement for future rehabilitation. These desires resulted in a 1583-ft-long bridge with no expansion joints between abutments. The addition of a crest vertical curve and bicycle lanes created the ability to eliminate all scuppers and downspouts from the bridge. Removal of drainage facilities from the bridge also limited right-of-way needs from the zoo and reduced direct runoff to Big Creek.

To accomplish this, a prestressed concrete I-beam superstructure was designed to "float" on top of six 210-ft-long arch spans with a spandrel column spacing of 42 ft. Nine AASHTO Type III beams support an 81-ft-wide deck, with four 12-ft-wide traffic lanes, two 5-ft-wide bicycle lanes, and two 10-ft-wide sidewalks.

Including the six main arch spans and five approach spans, the beams will be continuous across 35 spans. A combination of elastomeric and PTFE sliding bearings are necessary to accommodate the thermal movements. The beams will be composite with the

A Metroparks Zoo walkway crosses beneath the location of an arch span.

deck and will be connected transversely with continuity diaphragms. The beams were designed to account for deflection of the arches under live loads in addition to long-term creep and shrinkage effects. Thus, the design of the individual 42-ft-long beam spans between spandrel columns were superimposed with the design of a continuous 210-ft-long beam spanning each arch span, with the spandrel columns acting as flexible supports for the continuous span. The outcome was the need for additional prestressing strands near midspan of the arches, additional reinforcement in the deck over the arch span piers, and a longer length of extended strands at the continuity diaphragms.

Construction

The project went to bid in late August 2006 and had an original duration of almost 3 years. The contract was awarded to Kokosing Construction Company Inc. from Fredericktown, Ohio, with a low bid of $45,859,138. The project includes the construction of a new zoo entrance that was required to be completed and placed into use prior to demolition of the old structure, a mechanically stabilized earth wall at the north abutment, a shared-use path with soldier pile/concrete panel retaining walls, and minimal roadway work on the approaches.

Construction operations began in early October 2006 with preparations for the demolition. The contractor elected to use explosives to demolish the six main arch spans. One of the spans was over both the Norfolk Southern and CSX railroads, where access was difficult and "track time" was limited. A big challenge was coordinating work with both railroads simultaneously. The railroads were able to provide only a 48-hour window to remove the tracks, implode the structure, haul out the debris, and re-install the tracks.

Two other existing main arch spans cut through the Cleveland Metroparks Zoo, where zoo access would be impeded. The access path closure times were limited and traditional mechanical demolition techniques were neither desirable to the zoo authorities nor in the best interest of the animals.

Another of the main spans crossed over both the Big Creek and an old historic three-hinged arch bridge that required protection throughout the construction work. The contractor chose to construct a temporary bridge over the top of the historic bridge to serve as both protection during demolition and access across the creek and into the zoo.

Foundations for the structure consist both of footings on large drilled shafts and spread footings on hard shale. The footings, pier bases, and pier thrust blocks are all cast-in-place concrete. Due to the complexity of the thrust block construction (dense configuration of reinforcement, post-tensioning ducts, and mass concrete cooling tubes), the contractor chose to use self-consolidating concrete (SCC) for these placements.

Each arch line consists of three precast arch segments, as described above, that have a 1 ft 6 in. concrete closure placement between each segment. The end segments are erected first, with one end supported on a temporary steel tower and the other end bolted to a temporary support bracket attached to the cast-in-place concrete thrust block arm. The crown segments are later set utilizing a strong-back connection at one end and a temporary bolted connection at the other. After the closures are cast, the post-tensioning is performed, tying the segments together.

Precast concrete arch struts are installed between arch lines by bolting them to the face of the arches. Closure placements are required to encase the steel bracket connections and give the arch strut a uniform appearance.

Work has recently begun on the cast-in-place concrete spandrel columns and frames. The columns will extend up from the top of the arch lines, framing into transverse column caps. The column caps will support the prestressed concrete I-beams that in turn will support the deck.

Bridge construction is expected to be completed by the end of 2009. In the meantime, the local residents and all of the participating agencies are looking forward to the completion of this project and the enjoyment the new structure will provide to the citizens of Cleveland and to patrons of the zoo for decades to come. Once reopened, the bridge will again be a key connection across the Big Creek Valley, improving traffic operations on Fulton Road and allowing greater pedestrian and bicycle access across the valley and into the park below.

Gregory Kronstain is a construction project engineer with the Ohio Department of Transportation, District 12, Garfield Heights, Ohio, John Dietrick is director of bridge services for Michael Baker Jr. Inc., Cleveland, Ohio, and Brendan Finn is chief bridge engineer with the Cuyahoga County Engineer's Office, Cleveland, Ohio.

For more information on this or other projects, visit www.aspirebridge.org.

The Cotton Lane Bridge over the Gila River in Goodyear, Ariz., was created with a unique public/private partnership that involved the city, county, and two developers.

Exterior girders had textural decorations reflecting the desert environment cast into them with the use of formliners.

PUBLIC/PRIVATE PARTNERSHIP SUCCEEDS

by David Lawson, Michael Baker Jr. Inc.

Combination of local government and developers produces decorative, cost-efficient bridge design

Bridge designs often must meet the concerns of a variety of participants, and finding innovative ways to ensure all needs are met becomes even more acute as more private organizations join with public entities to fund bridge designs. That proved to be the case for the Cotton Lane Bridge over the Gila River in Goodyear, Ariz., where the Maricopa County Department of Transportation (MCDOT), as the lead agency, joined forces with the City of Goodyear (COGY) and two local developers. The resulting precast concrete design met everyone's needs and produced a strikingly attractive structure that met a reasonable budget and was produced on schedule.

As the city experienced strong growth, COGY and MCDOT officials recognized the need to alleviate traffic congestion in a region that was expanding with housing developments. They also wanted to provide an additional bridge crossing over the Gila River to improve the regional transportation system.

In achieving these goals, the various stakeholders had specific priorities. MCDOT, which transferred ownership to COGY upon completion, wanted to ensure the project was constructed quickly to support the local development and to improve the regional transportation network, setting a one-year construction schedule. The two contributing developers (Sonterra Partners and Estrella Mountain Ranch) emphasized the need for an attractive design to draw potential buyers to the development while remaining within budget. Meanwhile, the Flood Control District of Maricopa County (FCDMC) wanted to ensure the new crossing preserved the area's rich environmental resources and unique river wildlife.

Meeting these needs was complicated by the requirement that the structure optimize the modest construction budget. To achieve this, Michael Baker Jr., serving as the prime consultant, worked with COGY, MCDOT, FCDMC, and the developers through a

profile

COTTON LANE BRIDGE / GOODYEAR, ARIZONA

LEAD AGENCY: Maricopa County Department of Transportation

ENGINEER: Michael Baker Jr. Inc., Phoenix, Ariz.

CONSTRUCTION MANAGER: Tristar Engineering & Management Inc., Chandler, Ariz.

GEOTECHNICAL INVESTIGATION: Ricker Atkinson McBee Mormann & Associates, Tempe, Ariz.

AWARDS: *Best Bridge With Spans Between 75 and 150 Feet, Co-Winner, Precast/Prestressed Concrete Institute's Design Awards 2008; Top 20 Project, Southwest Contractor magazine, 2008; 2008 Honor Award, Arizona chapter of the American Council of Engineering Companies.*

Construction Management at Risk (CMAR) partnership.

COGY, MCDOT, and the developers were all financial participants in the bridge and corresponding roadway's cost. Kiewit Western Co. was selected early in the design process to serve as the construction manager and advisor during design. It also served as general contractor. The CMAR format allowed Baker and the entire design team to evaluate alternatives quickly during design with more accurate estimation of construction cost, constructability, and construction time.

The final design consisted of a 17-span bridge using 12 lines of AASHTO Type VI-modified girders per span. Each span is approximately 121 ft 6 in., resulting in a 2067-ft-long bridge. All interior girders are modified to a 6-in.-thick web as a result of moving the side forms closer together. This provides a 26-in.-wide bottom flange and 40-in.-wide top flange. Interior girders are spaced at 9 ft 5 in. centers.

The fascia girders were modified to accommodate an aesthetic formliner that imparted textures that are overlain by two-dimensional illustrations of geckos. This pattern has a maximum ¾ in. relief, 3 ft 6 in. tall by the full length of the girder. To achieve the flat face to apply the pattern, both top and bottom flanges on the exterior face of the girder were blocked off during casting, creating a "C" or channel shaped girder. In addition, the web was increased to 14 in. thick by adding 6 in. to the outside face. The resulting top flange is 2 ft 7 in.

Alcoves with benches were created along the bridge's length to invite pedestrians to linger and enjoy the scenery, while two bat lodgings were created beneath the bridge to accommodate up to 8000 bats. The alcoves along the bridge are each supported by two precast concrete corbels, which served as falsework during construction, reducing project cost and construction time.

The substructure consisted of cast-in-place drilled shafts, piers, and bent caps.

The precaster, who was brought onto the project early due to the use of a Construction Management at Risk contracting method, supplied 204 Type VI-modified AASHTO girders in 17 spans, each approximately 122 ft long, to create the 2067-ft-long bridge.

Stakeholder Input and Environmental Assessment

In addition to the four funding groups, many other stakeholders were involved in the design and construction of the project. These stakeholders included local schools, a number of city, county, state, and federal governmental agencies, irrigation districts, railroad, utilities, local residents, and business owners.

With these inputs, designers analyzed several bridge-design alternatives relative to hydraulics, on-site and off-site hydrology, sediment transport, cost, environmental options, and drainage-infrastructure impacts to the Gila River corridor and floodplain.

Drainage design included a review of the Gila River hydraulic and sediment-transport modeling report, and the design and modeling of various alternatives in compliance with the requirements. The alternatives consisted of a longer bridge without floodplain impact and a shorter bridge with improvements to the floodplain. The selected alternative was the shorter bridge with corresponding improvements to the floodplain.

Permitting presented several challenges, since the Gila River is among the jurisdictional waters of the United States, requiring various permits. This effort led to the largest Section 404 permit in Arizona's history.

17-SPAN PRECAST, PRESTRESSED CONCRETE AASHTO I-GIRDER BRIDGE / CITY OF GOODYEAR, OWNER

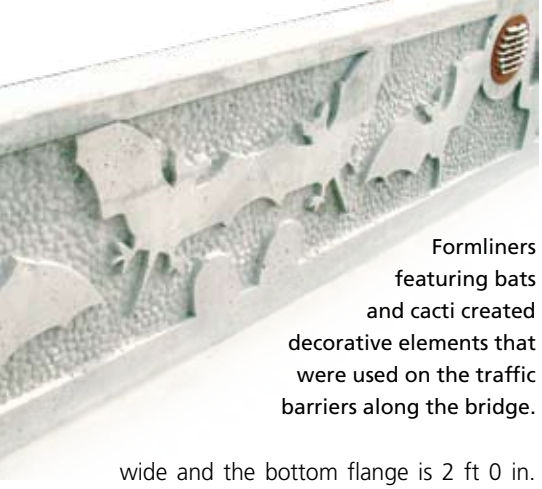
LANDSCAPE ARCHITECT: Corral Dybas Group Inc., Phoenix, Ariz.

PRIME CONTRACTOR: Kiewit Western Company, Phoenix, Ariz.

PRECASTER: Tpac—A Division of Kiewit Western Co., Phoenix, Ariz., a PCI-certified producer

BRIDGE DESCRIPTION: 2067-ft-long bridge featuring 17 spans of AASHTO Type VI-modified precast, prestressed concrete girders, including exterior girders with decorative designs created with form liners; precast concrete corbels supporting circular pedestrian alcoves; and cast-in-place substructure and deck

BRIDGE CONSTRUCTION COST: $27 million



Formliners featuring bats and cacti created decorative elements that were used on the traffic barriers along the bridge.

wide and the bottom flange is 2 ft 0 in. wide. This modified edge girder contains fifty-three 0.6-in.-diameter strands—41 straight and 12 harped. The specified concrete strength was 6500 psi at 28 days and 5200 psi at release. More details of design of the horizontally asymmetric exterior girders may be found in a paper by the author.[1]

The 8-in.-thick deck has an out-to-out width of 114 ft 9½ in. with a 16-ft-wide striped median and provides, in each direction, a 6-ft-wide outside sidewalk protected by a traffic barrier to the inside and pedestrian railing to the outside, a 5-ft 5-in.-wide bicycle lane, and three 12-ft-wide traffic lanes (two striped now and one in the future). Beneath the deck, the bridge carries a 24-in.-diameter reclaimed water line, two 30-in.-diameter water lines, and a large utility bank (12 conduit lines).

Thirty-two circular pedestrian alcoves, placed on both sides of the bridge at each pier location, invite pedestrians to linger and enjoy the scenery. Each alcove is supported by two precast concrete corbels, which were designed to serve as the falsework during construction, reducing project cost and construction time.

In an effort to achieve cost savings without compromising any of the stakeholders' interests, the team utilized creative cost saving strategies. Precast concrete was used where possible to minimize construction time, cost, and adverse impact to the environment. Additionally, a static drilled shaft load test utilizing the Osterberg load cell was performed during early design. Due to the higher reliability of the soil response obtained through the use of this load test, a reduced safety factor, as permitted by the AASHTO LRFD specifications was permitted in design. Savings in the foundation cost far outweighed the cost of the load test and resulted in net savings of more than $1 million to the project.

The bridge's substructure, including columns and bent caps, is cast-in-place concrete. Each column is founded on a single, 72-in.-diameter drilled shaft approximately 105 ft deep.

The Cotton Lane Bridge was a project of firsts and extremes, but the innovative design approach chosen and solutions incorporated into the project exceeded the needs of the owner and client. The design exemplifies environmentally responsive and responsible engineering achieved through continual collaboration of all project stakeholders. The versatility of precast concrete produced a cost-efficient and aesthetically unique bridge that pleased everyone involved.

From forging a creative public/private funding partnership to using unique aesthetics and the CMAR process, the solutions created for this project can serve as a prototype for future bridge-engineering challenges in achieving the collective goals of context sensitivity, project streamlining, and cost efficiency.

References

1. Lawson, David J., and G. P. Wollmann, 2007, "Advanced Aesthetic Embedment in Prestressed Girder," Proceedings of the PCI-FHWA National Bridge Conference, October 22-24, Phoenix, Ariz., 10 pp.
2. Lawson, David J., Ed Corral, and Larry N. Sullivan, 2007, "Cotton Lane Gila River Bridge—Integration of Environment and Infrastructure," Proceedings of the PCI-FHWA National Bridge Conference, October 22-24, Phoenix, Ariz., 11 pp.

David Lawson is a structural engineer with Michael Baker Jr. Inc. in Phoenix, Ariz.

For more information on this or other projects, visit www.aspirebridge.org.

Sustainability and Aesthetic Impact

The Construction Management at Risk (CMAR) process allowed local precasters to add their valuable input to the design process, contributing to the development of effective precast concrete alternatives. This ensured that critical construction elements were not overlooked and that the most efficient solutions to each challenge were discussed, refined, and implemented.

Creating a Natural Design[2]

Recognizing that this bridge would forever change the natural environment of this portion of the Gila River, the Maricopa County Department of Transportation inspired the team to frame its conceptual design around the question, "How would nature build this?" The answer produced numerous design elements to support the natural environment and wildlife at the construction site while also meeting goals for incorporating sustainable design wherever possible.

The bridge features a low-profile vertical curve, allowing the minimized-arch shape to blend visually with the backdrop of the Estrella Mountains. Sustainability measures also were incorporated into the precast concrete components in a variety of ways. Precasting the components minimized construction waste, and concrete remaining after casting was recycled for use with other ongoing projects. The precast concrete components were cast in nearby Phoenix, minimizing transportation costs. Precast products incorporated Type F fly ash in the concrete mixture, reducing the amount of Portland cement.

Amenities Enhance Design

Inspired by the weathered desert surroundings, the design features exterior girders that used custom form liners to create textures that are overlain by two-dimensional illustrations of geckos. The columns used construction techniques to create fossil-like patterns of prehistoric creatures and plants on their sides. Incorporating the aesthetics directly onto the fascia girders decreased construction time by eliminating the need to hang aesthetic-patterned panels after girder placement. Bats and cacti also were cast onto the back of the traffic barrier to further enhance the desert-themed aesthetics and visual connection to the environment.

To support the wildlife of the river ecosystem, designers created enclosed lodgings to sustain the bat populations living near the river. Baker worked closely with the Arizona Game & Fish Department to incorporate two appropriate bat lodgings on the underside of the bridge, each of which can accommodate up to 4000 bats. Additionally, to minimize pollution caused by excess illumination and comply with the city's "dark sky" requirements, designers created shortened light poles with low-intensity lighting.

photo courtesy of PCI and Mid-States Concrete Industries

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To learn more about PCI certification and PCI, visit **www.pci.org/certification** or contact Dean Frank, P.E., Director of Quality Programs, at (312) 583-6770 or dfrank@pci.org

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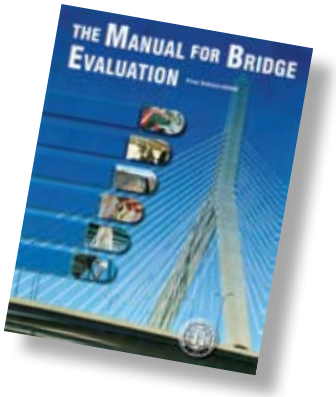
The AASHTO Manual for Bridge Evaluation

by Matthew M. Farrar, Idaho Transportation Department



With the publication in 2008 of the First Edition of the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Bridge Evaluation* (MBE), AASHTO completes an up-to-date trio of specifications for the design, construction, and evaluation of bridges.

The MBE contains important information for bridge owners regarding bridge management and operations for existing bridges. As stated in the preface to the MBE, "Long anticipated and painstakingly developed, *The Manual for Bridge Evaluation*, First Edition, offers assistance to Bridge Owners at all phases of bridge inspection and evaluation."

It sometimes comes as a surprise to bridge practitioners that bridge owners permit truck loads as much as 10 times larger than the original design truck to cross their bridges. The MBE provides bridge owners with a state-of-the-art specification to determine the safe capacities of their bridges with consideration of bridge condition.

As far back as 1941, the American Association of State Highway Officials (AASHO) *Standard Specification for Highway Bridges* included provisions for the load rating of existing bridges. Around 1970, AASHTO combined load rating specifications and bridge condition evaluation and inspection procedures into a stand-alone publication titled the AASHTO *Manual for Maintenance Inspection of Bridges*. This manual evolved into the *Manual for Condition Evaluation of Bridges* in 1994.

In 2003, AASHTO published the *Guide Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) for Highway Bridges* to reflect the Load and Resistance Factor Design (LRFD) Specifications that AASHTO had already adopted.

The 2008 First Edition of the AASHTO MBE supersedes the publications mentioned above and has been developed to assist bridge owners by establishing inspection procedures and evaluation practices that meet the National Bridge Inspection Standards (NBIS). The MBE comprises 548 pages and has been divided into the following eight sections, with each section representing a distinct phase of an overall bridge inspection and evaluation program. The manual also contains numerous load rating examples.

Section 1: Introduction

Section 1 contains introductory and background information on the maintenance inspection of bridges as well as definitions of general interest terms.

Section 2: Bridge Files (Records)

Key components of a comprehensive bridge file are defined in Section 2. The record of each bridge in the file provides the foundation against which changes in physical condition can be measured.

Section 3: Bridge Management Systems

A bridge management system is an effective tool in allocating limited resources to bridge related activities. An overview of bridge management systems is included in Section 3.

Section 4: Inspection

The types and frequency of field inspections are discussed in Section 4, as are specific inspection techniques and requirements.

Section 5: Material Testing

Conditions at a bridge site or the absence of information from original construction may warrant more elaborate material tests. Various testing methods are discussed in Section 5.

Section 6: Load Rating

Section 6 discusses the load rating of bridges and includes the Load and Resistance Factor (LRFR) method, the Load Factor (LFR) method and the Allowable Stress (ASR) method. No preference is placed on any rating method. The rating procedures presented for the LRFR method recognize a balance between safety and economics. In most cases, a lower target reliability than design has been chosen for load rating at the strength limit state. The LRFD calibration reported a target LRFD reliability index β of 3.5. The LRFR procedures adopt a reduced target reliability index of approximately 2.5 calibrated to past AASHTO operating level load rating. This value was chosen to reflect the reduced exposure period, consideration of site realities, and the economic considerations of rating versus design. The methodology for the load and resistance factor rating of bridges is comprised of three distinct procedures: 1) design load rating, 2) legal load rating, and 3) permit load rating. The results of each procedure serve specific uses and also guide the need for further evaluations to verify bridge safety or serviceability.

Section 7: Fatigue Evaluation of Steel Bridges

The evaluation of existing steel bridges for fatigue is discussed in Section 7.

Section 8: Nondestructive Load Testing

Load test procedures are described in Section 8. Load testing is the observation and measurement of the response of a bridge subjected to controlled and predetermined loadings without causing changes in the elastic response of the structure. Load tests can be used to verify both component and system performance under a known live load and provide an alternative evaluation methodology to analytically computing the load rating of a bridge.

The successful application of the MBE is directly related to the organizational structure established by the bridge owner. Such an organization should be both effective and responsive so that the unique characteristics and special problems of individual bridges are considered in developing an appropriate inspection plan and load capacity determination.

The AASHTO *Manual for Bridge Evaluation*, First Edition, may be ordered from AASHTO Publications at 800-231-3475 or obtained online at https://bookstore.transportation.org.

Matthew M. Farrar is state bridge engineer, Idaho Transportation Department, Boise, Idaho, and serves on the AASHTO Subcommittee on Bridges and Structures, and its Technical Committee T-18, Bridge Management, Evaluation, and Rehabilitation.

Expanded Shale, Clay, and Slate Institute

The Expanded Shale, Clay & Slate Institute (ESCSI) is the international trade association for manufacturers of expanded shale, clay, and slate (ESCS) aggregates produced using a rotary kiln. The institute is proud to sponsor *ASPIRE*™ magazine.

Sustainable concrete bridges must be durable bridges. Durable concrete must have both low permeability and few or no cracks. Lightweight aggregate concrete has been shown to have enhanced properties in both of these issues. The enhanced performance of lightweight concrete has been attributed to a number of factors including:

- Internal curing provided by premoistened lightweight aggregate;
- Elastic matching of the lightweight aggregate and hardened paste;
- Excellent bond between the lightweight aggregate and paste; and
- Lower modulus of elasticity and higher strain capacity.

The enhanced durability of lightweight concrete, combined with the obvious benefits of reduced density, results in structures that will last longer. Such structures conserve valuable natural resources as well as scarce funds for bridge construction and rehabilitation.

For more information on lightweight concrete, including references discussing the factors mentioned above, please visit www.escsi.org. The members of ESCSI look forward to assisting owners, designers, and concrete producers in using lightweight concrete for bridges.

CONCRETE CONNECTIONS

Concrete Connections is an annotated list of websites where information is available about concrete bridges. Fast links to the websites are provided at www.aspirebridge.org.

IN THIS ISSUE

www.trb.org/CRP/NCHRP/NCHRPprojects.asp
This website provides a list of all National Cooperative Highway Research Program (NCHRP) projects since 1989 and their current status. Research Field 12—Bridges generally lists projects related to bridges although projects related to concrete materials performance may be listed in Research Field 18—Concrete Materials. Click on Research Field 12 and scroll down to NCHRP 12-80 for a description of the research being performed by PBS&J.

www.paturnpike.com/ConstructionProjects/arb
This Pennsylvania Turnpike project website contains additional information and photographs of the I-76 Allegheny River Bridge.

www.dot.state.co.us/US285/index.cfm
This Colorado Department of Transportation website contains information about the widening of U.S. 285 from Foxton Road to Richmond Hill. Photographs of early construction are available.

https://bookstore.transportation.org
Visit this website to order a copy of the AASHTO Manual for Bridge Evaluation, other AASHTO publications, or just to browse the bookstore.

http://cms.transportation.org/?siteid=34&pageid=1484
This website lists the preliminary versions of the balloted items from the AASHTO 2008 Subcommittee on Bridges and Structures meeting. Balloted items in pdf format may be downloaded by scrolling to the bottom of the page.

Environmental

http://environment.transportation.org/
The Center for Environmental Excellence by AASHTO's Technical Assistance Program offers a team of experts to assist transportation and environmental agency officials in improving environmental performance and program delivery. The *Practitioner's Handbooks* provide practical advice on a range of environmental issues that arise during the planning, development, and operation of transportation projects.

http://www.environment.transportation.org/teri_database
This website contains the Transportation and Environmental Research Ideas (TERI) database. TERI is the AASHTO Standing Committee on Environment's central storehouse for tracking and sharing new transportation and environmental research ideas. Suggestions for new ideas are welcome from practitioners across the transportation and environmental community.

Bridge Technology

www.aspirebridge.org
Previous issues of *ASPIRE*™ are available as pdf files and may be downloaded as a full issue or individual articles. Information is available about subscriptions, advertising, and sponsors. You may also complete a reader survey to provide us with your impressions about *ASPIRE*. It takes less than 5 minutes to complete.

www.nationalconcretebridge.org
The National Concrete Bridge Council (NCBC) website provides information to promote quality in concrete bridge construction as well as links to the publications of its members.

www.hpcbridgeviews.org
This website contains 53 issues of *HPC Bridge Views*, an electronic newsletter published jointly by the FHWA and the NCBC to provide relevant, reliable information on all aspects of high-performance concrete in bridges. Sign up at this website for a free subscription.

Bridge Research

www.tfhrc.gov/ltbp/index.htm
This FHWA website provides information about the Long-Term Bridge Performance Program—a major new strategic initiative designated as a flagship research project. The LTBP program is intended to be a 20-year undertaking with the global objective of collecting scientific quality data from the Nation's highway bridges.

http://www.fhwa.dot.gov/pavement/concrete/asr.cfm
A quarterly newsletter titled *Reactive Solutions* is available to download at this website. *Reactive Solutions* provides general information about alkali-silica reactivity (ASR) as well as updates on the FHWA ASR Development and Deployment Program.

http://rip.trb.org/
The Transportation Research Board's Research in Progress (RiP) website contains the Research In Progress (RiP) Database of over 11,800 current or recently completed transportation research projects. A data-entry system allows users in state departments of transportation, the U.S. Department of Transportation, and university transportation centers to add, modify, and delete information on their current research projects.

www.trb.org/news/blurb_detail.asp?id=8693
NCHRP Report 584, *Full-Depth Precast Concrete Bridge Deck Panel Systems* examines recommended guidelines and the AASHTO LRFD specifications language for design, fabrication, and construction of full-depth precast concrete bridge deck panel systems. Recommended guidelines and proposed revisions to the LRFD specifications language are available as online appendices.

http://www.trb.org/news/blurb_detail.asp?id=9627
NCHRP Report 628, *Self-Consolidating Concrete for Precast, Prestressed Concrete Bridge Elements* explores recommended guidelines for the use of self-consolidating concrete (SCC) in precast, prestressed concrete bridge elements. The report examines the selection of constituent materials, proportioning of concrete mixtures, testing methods, fresh and hardened concrete properties, production, and quality control issues, and other aspects of SCC.

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Submission Requirements

Individuals wishing to present a contribution (paper or poster) at the technical sessions are invited to submit an abstract online. **The deadline for receipt of abstracts is June 15, 2009. Abstracts should be submitted electronically to www.fib2010washington.com**

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CONCRETE BRIDGES IN LEE COUNTY, FLORIDA

by Paul Wingard, Clay Simmons, and Ehab Guirguis, Lee County, Fla.

A view from under the Sanibel Island Bridge A revealing its unique piers.

Lee County is located along the picturesque southwest Gulf Coast of Florida and includes the famous Sanibel and Captiva Islands. The Lee County Department of Transportation (LCDOT) is charged with the maintenance responsibility of 128 bridge structures within Lee County. LCDOT's bridges represent approximately 1.16% of the total number of bridges in the state of Florida.

The majority of these bridges are located in a high humidity, salt-water environment, so corrosion resistance is of utmost importance to the service lives of our bridges. LCDOT has found that bridges constructed of reinforced concrete fulfill these needs nicely and provide reliable service life to support growing traffic demands as our population continues to increase.

Twenty-eight of our 128 bridges, or 22%, are concrete box culverts crossing small to medium width canals and bodies of water where navigation is not a consideration.

Thirty-nine bridges (31%) are constructed using precast, prestressed concrete slabs. These bridges are usually located over medium-width bodies of water and small navigable canals.

Bridges over Lee County's largest bodies of water, including the newly completed Sanibel Causeway Bridges, are constructed with precast, prestressed concrete piles and beams. This is typical of the practice for such bridges located across the state of Florida. These large bridges represent an additional 19 structures or 15% of Lee County's overall inventory. Included in this category are three functioning drawbridges.

The remainder of those qualifying as bridges according to the Federal Highway Administration (FHWA) definition as having an effective span length of 20 ft or greater, consist primarily of small concrete culverts providing crossings over such features as drainage ways. All public bridges in Lee County that meet this FHWA bridge definition are inspected by the Florida Department of Transportation (FDOT) at least once every 2 years.

With an average age of 25.7 years, we are pleased with the performance of reinforced concrete as our primary bridge construction material. None of Lee County's bridges are currently classified as structurally deficient according to FHWA/FDOT condition inspection and rating guidelines.

In addition to material selection, Lee County believes that preventative maintenance routines play a significant role in keeping the county's bridges in the best possible condition. LCDOT is fortunate to have in-house bridge repair crews, comprising seven bridge technicians that handle most required maintenance including concrete spall repairs, joint repairs, guardrail repairs, vessel fender repairs, routine substructure cleaning, and drawbridge maintenance. Qualified contractors are procured for larger repairs and long-term comprehensive bridge rehabilitation projects.

In 2007, LCDOT completed construction of the Sanibel Causeway Bridges. The three bridges were constructed using precast, prestressed concrete bulb-tee beams. The bridges have a total length of approximately 1.6 miles and contain 6.6 miles of precast beams. They use 13,339 yd^3 of concrete in the superstructure, 14,087 yd^3 of concrete in the substructure and 28 miles of 30-in.-square, hollow, precast, prestressed concrete piles. In addition to the piles and beams, much of the substructure, the footings and columns, were also precast elements, constructed at a temporary casting yard set up close-by within Lee County.

In the future, LCDOT will continue to use concrete as our primary construction material to build new bridges as an efficient, cost-effective, and timely material for bridge construction along the Gulf Coast region of Florida.

Paul Wingard is deputy director, Department of Transportation, Clay Simmons is division director, Department of Transportation Operations, and Ehab Guirguis is bridge engineer, all with Lee County, Fla.

The Midpoint Bridge was constructed in 1997.

The three Sanibel Island Bridges were completed in 2007 and have a total length of 1.6 miles. Photo: Florida Aerial Services Inc.

Silica Fume Association

The Silica Fume Association (SFA), a not-for-profit corporation based in Delaware, with offices in Virginia and Ohio, was formed in 1998 to assist the producers of silica fume in promoting its usage in concrete. Silica fume, a by-product of silicon and ferro-silicon metal production, is a highly-reactive pozzolan and a key ingredient in high performance concrete, dramatically increasing the service-life of structures.

The SFA advances the use of silica fume in the nation's concrete infrastructure and works to increase the awareness and understanding of silica fume concrete in the private civil engineering sector, among state transportation officials and in the academic community. The SFA's goals are two-fold: to provide a legacy of durable concrete structures and to decrease silica fume volume in the national waste stream.

Some of the recent projects completed by the SFA, under a cooperative agreement with the Federal Highway Administration (FHWA), include:

- The publication of a *Silica Fume User's Manual*—the manual is a comprehensive guide for specifiers, ready mixed and precast concrete producers, and contractors that describes the best practice for the successful use of silica fume in the production of high performance concrete (HPC).
- The introduction of a Standard Reference Material (SRM)® 2696 Silica Fume for checking the accuracy of existing laboratory practices and to provide a tool for instrument calibration. This SRM is available from the National Institute of Standards and Technology (NIST).

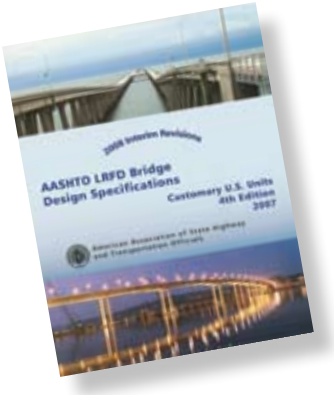
A much anticipated research program nearing completion by the SFA is the testing of in-place silica fume concrete under service conditions. At the conclusion of this research the results will demonstrate the benefit of silica fume concrete's unparalleled long-term performance. For more information about SFA, visit www.silicafume.org.

2009 Interim Changes Part 2

by Dr. Dennis R. Mertz

In the Winter 2009 issue of *ASPIRE,*™ three of the five 2008 concrete-structures agenda items considered and adopted by the American Association of State Highway and Transportation Officials (AASHTO) Subcommittee on Bridges and Structures (SCOBS) at their annual meeting in Omaha, Neb., in May 2008, were reviewed. These agenda items along with the complete agenda for the May 2008 SCOBS meeting can be found on the AASHTO website at http://cms.transportation.org/?siteid=34&pageid=1484. These agenda items represent revisions and additions to the AASHTO LRFD Bridge Design Specifications, which will become the 2009 interim changes. A review of the final two concrete-structures items, Agenda Items 61 and 62 follows.

Agenda Item 61 clarifies the provisions for prestress losses of Article 5.9.5 of the LRFD Bridge Design Specifications. Previous revisions to Article 5.9.5 were based upon NCHRP Report 496, "Prestress Losses in Pretensioned High-Strength Concrete Bridge Girders," by Tadros et al., extending the provisions to concretes with specified compressive strengths up to 15 ksi. Agenda Item 61 provides clarification on the application of the research findings. The research only addressed normal weight concretes. Thus, this agenda item restricts the application of Article 5.9.5.3.1 to normal weight concretes. Further, the lump-sum time-dependent losses of Table 5.9.5.3-1 were not investigated in the NCHRP study. Thus, the losses in the table are not applicable to concretes with specified compressive strengths above 10 ksi. Finally, the agenda item clarifies that the losses of Table 5.9.5.3-1 may be used for structural lightweight concrete members other than those made with composite slabs provided the values in the table are increased by 5.0 ksi. In previous versions of the LRFD Specifications, the 5.0 ksi increase was mandatory.



Agenda Item 62 creates a new appendix to Section 5, Concrete Structures, titled Appendix C5—Upper Limits for Articles Affected by Concrete Compressive Strength. This new appendix is referenced in Article C5.4.2.1. Appendix C5 tabulates the articles in Section 5 that are a function of concrete compressive strength and for each indicates their applicability in terms of the upper bound of specified compressive strength, either 10 or 15 ksi, for each article. In addition, the agenda item limits the applicability of the equation of direct tensile strength of Article C5.4.2.7 to normal weight concrete with specified compressive strengths up to 10 ksi.

These two concrete-structures agenda items, along with the three discussed in the previous issue of *ASPIRE*, are included in the 2009 interim changes to the AASHTO LRFD Bridge Design Specifications. AASHTO Technical Committee, T-10, Concrete Design, continues to work during their four annual meetings on working agenda items which may potentially become revisions and additions to the AASHTO documents. As these working agenda items are moved to the subcommittee's ballot and are subsequently considered as agenda items and adopted as interim changes, they will be discussed in this column.

Mattaponi River Spliced Girder Bridge,
West Point, Virginia

Lalon Shah Precast Segmental Bridge,
Bangladesh

Hood Canal Floating Bridge,
Seattle, Washington

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www.pbworld.com

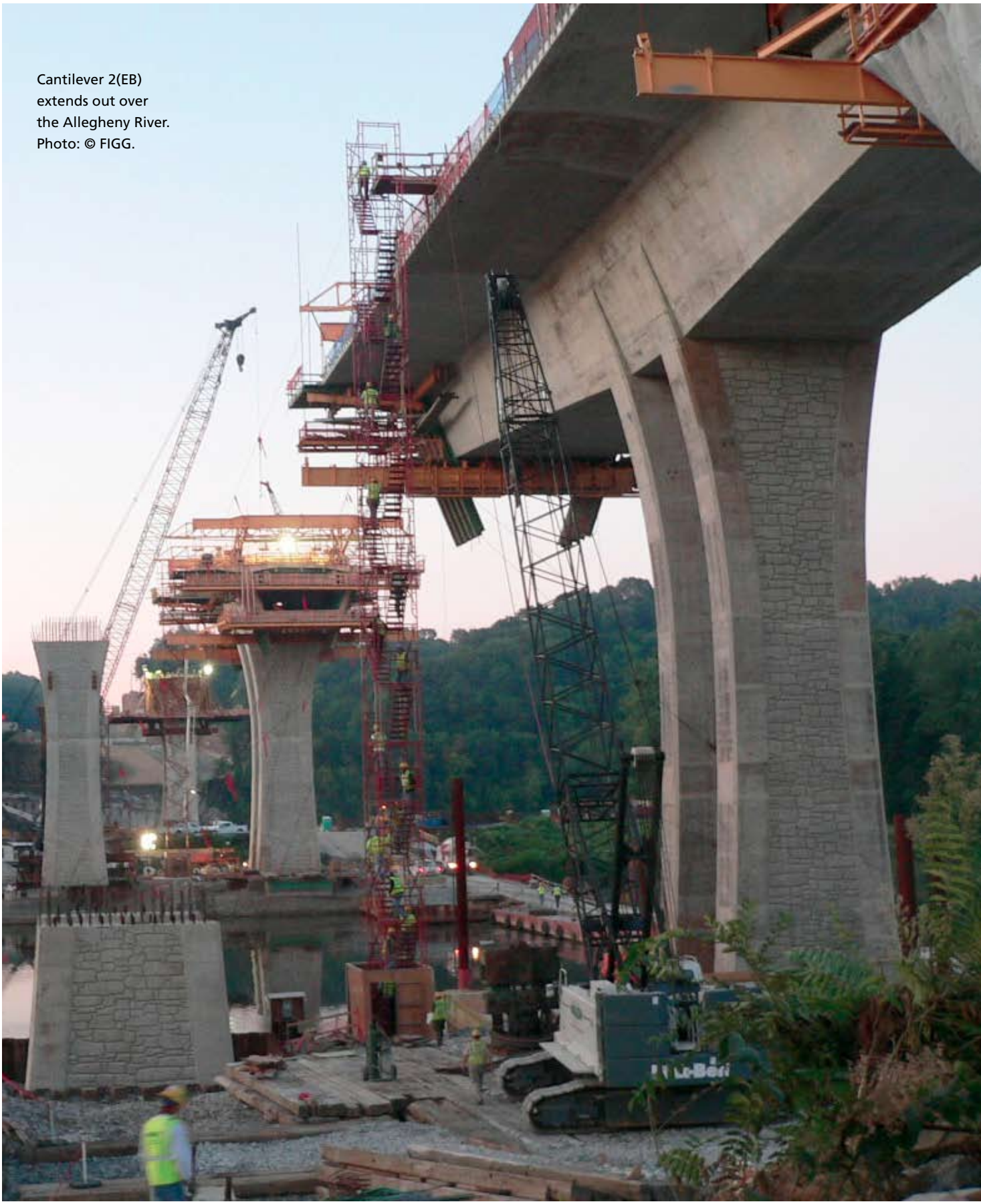
PARSONS BRINCKERHOFF

Sound Transit Guideway Structure,
Seattle, Washington

Arthur Ravenel Jr. (Cooper River)
Cable-Stayed Bridge,
Charleston, South Carolina

Piers from the bridge are textured and stained to complement the landscape from the golf course at Oakmont Country Club.
Photo: © FIGG.

The variable depth superstructure creates an arching form over the Allegheny River.
Photo: © FIGG.



Cantilever 2(EB) extends out over the Allegheny River. Photo: © FIGG.

Once the superstructure cantilevers were 184 ft and 192 ft long, forms were lowered onto a barge in one piece, dismantled into smaller sections, and then relocated to a new pier for the next cantilever construction. Photo: © FIGG.

FORTY FOOT PEDESTRIAN BRIDGE / TOWAMENCIN TOWNSHIP, MONTGOMERY COUNTY, PENN.

Photo: Simone Collins Landscape Architecture.

FORTY FOOT PEDESTRIAN BRIDGE / TOWAMENCIN TOWNSHIP, MONTGOMERY COUNTY, PENN.

Photo: Simone Collins Landscape Architecture.

The Forty Foot Bridge under night traffic reveals many of its aesthetic features. Photo: Simone Collins Landscape Architecture.

Photo: Simone Collins Landscape Architecture.

The 13-in.-deep haunches on the box beams and fascia panels can be easily seen with the deck forms in place. Providing haunches simplified forming, tying reinforcement, and placing concrete for the cambered deck. Paint on the deck form outlines the shape of a cast-in-place concrete planter. Photo: Simone Collins Landscape Architecture.

Structural Components:

Abutments—conventional cast in place with structural pylons

Retaining Walls—conventional precast MSE panels and caps, with geogrid reinforcing

Superstructure—hybrid design – with three conventional precast box girders and two custom, cast in place fascia beams

Deck—Cast in place, exposed aggregate structural deck

Landscape Planters—custom, cast in place planter walls on structural deck

Architectural Wingwalls—custom, precast panels, caps and finials, cladding structural pylons

Sloped Walls—conventional concrete paver blocks

FORTY FOOT PEDESTRIAN BRIDGE / TOWAMENCIN TOWNSHIP, MONTGOMERY COUNTY, PENN.

Photo: Simone Collins Landscape Architecture.

FORTY FOOT PEDESTRIAN BRIDGE / TOWAMENCIN TOWNSHIP, MONTGOMERY COUNTY, PENN.

Photo: Simone Collins Landscape Architecture.

FORTY FOOT PEDESTRIAN BRIDGE / TOWAMENCIN TOWNSHIP, MONTGOMERY COUNTY, PENN.

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Photo: Simone Collins Landscape Architecture.

FORTY FOOT PEDESTRIAN BRIDGE / TOWAMENCIN TOWNSHIP, MONTGOMERY COUNTY, PENN.

Photo: Simone Collins Landscape Architecture.

Forty Foot Road Pedestrian Bridge:
Integrating Aesthetics and Engineering

William Collins, RLA, ASLA, Simone Collins Landscape Architecture, Berwyn, PA
John Ruff, P.E., Senior Structural Engineer, QBS International Inc. Pennsauken, NJ
Kristen York, P.E., McMahon Associates Inc., Fort Washington, PA
Bashar S. Qubain, Ph.D., P.E., President, GeoStructures Inc., King of Prussia, PA

ABSTRACT

Forty Foot Road Pedestrian Bridge is an 80-foot long by 40-foot wide, single span, signature bridge over a 5-lane Pennsylvania highway, and the featured centerpiece of a "context sensitive design" highway infrastructure project completed in 2007 to create transportation improvements through a redeveloping town center. This case study offers:

- *Details of how aesthetics were incorporated into the structure during engineering, as an alternative to "applying" façade treatments after engineering.*
- *The attributes of concrete as the preferred structural and artistic material to achieve economy, longevity, and a seamless aesthetic between project engineering, bridge design, and site elements.*
- *Innovative engineering of a structural stringer beam to incorporate safety functions of concrete parapets and sound dampening functions of sound walls within the new architectural "fascia" beam design.*
- *Design of sloped "paver" retaining walls supported by MSE reinforcement.*
- *Brief context of how the local municipality conducted a 14-year process to comprehensively plan, justify, design, secure funding, and construct the $13 Million highway realignment and pedestrian bridge project in partnership with Pennsylvania Department of Transportation (PennDOT).*
- *Value-added design features, materials and techniques as smart, life-cycle investments to reduce maintenance costs, and create incentives for private development partnerships.*
- *Green investment in bridge infrastructure to save energy use.*

KEY WORDS

Forty Foot Road Pedestrian Bridge Aesthetics Context Sensitive Design Concrete Art Form Liners PennDOT MSE Simone Collins Landscape Architecture QBS Engineering McMahon Associates GeoStructures Towamencin Township RoadCon.

INTRODUCTION

Figure 1 *- Forty Foot Road Pedestrian Bridge is an 80-foot long by 40-foot wide, single span, signature bridge over a 5-lane Pennsylvania highway, and the featured centerpiece of a "context sensitive design" highway infrastructure project to create transportation improvements through a redeveloping town center. Completed in 2007.*

SITE / LOCATION

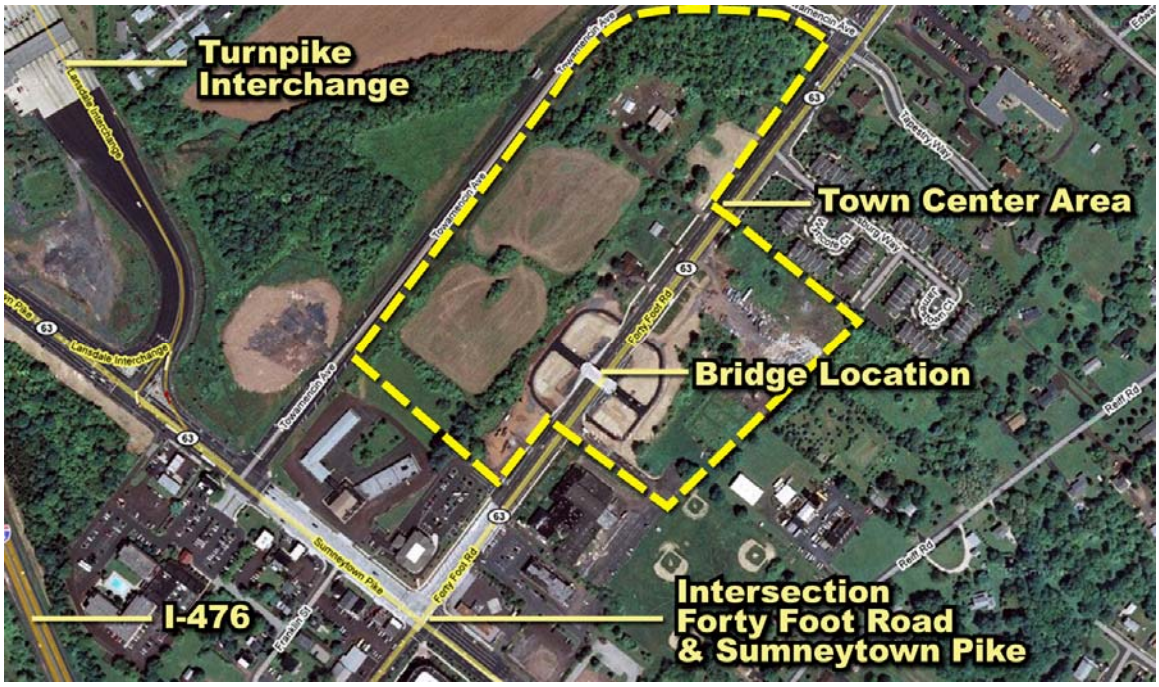


Figure 2 *– The new bridge is located in the heart of the town center project area and constructed as part of the roadway improvements <u>before</u> development of surrounding parcels. Aerial photo shows bridge and four pedestrian approaches that will be replaced with streetscape improvements as part of private developments within the adjacent quadrants.*

HISTORICAL CONTEXT OF THE TOWN CENTER

In the 1950's, the Northeast Extension of the Pennsylvania Turnpike (I-476) was cut through the heart of Kulpsville, in Montgomery County, Pennsylvania – razing much of the historic village to build the new superhighway and the local "Lansdale" exit." The Lansdale interchange is the first exit north of the primary east-west Turnpike, and the new highway access favored local commercial agribusinesses, resulting in increased truck and commuter traffic congestion on the connecting arterial roads. Local access to State Route 63 (aka Forty Foot Road) developed organically without an access management strategy to prevent traffic flow from slowing along the entire village corridor. Marginal businesses struggled in this degraded, highway "strip" environment. After 40 years, little integrity of the village fabric remained and much of the building stock within the project area was devalued.

By 1990, intense residential and industrial growth around this node had still not triggered improvements to state roads locally, as the Pennsylvania Turnpike Commission unveiled plans to increase the Lansdale toll plaza from four booths to ten, without proposing comparable improvements to the receiving roads. Facing a looming traffic gridlock, the local municipality, Towamencin Township, took responsibility as the lead partner to plan a solution.

COMMUNITY PLANNING ESTABLISHES NEED FOR A PEDESTRIAN BRIDGE

The Towamencin "Town Center" began with a vision in the early 1990's to integrate transportation improvements and land use planning. The Township commissioned economic studies to determine which market sectors could flourish in a new town center at this transportation hub. These economic projections were used to inform an iterative land use planning process and to refine highway plans, based on traffic projections for regional through traffic and traffic to be generated by a new town center "build out."

A new village "overlay" zoning ordinance and Town Center Design Manual were both created and adopted to address the proposed transportation improvements by establishing the parameters and level of quality for future village development.

The original purpose of the project was to improve the intersection and approaches of Sumneytown Pike and Forty Foot Road (both State Route 63), and to alleviate congestion and improve safety. Traffic studies determined that widening two-lane Forty Foot Road to five lanes would be necessary to accommodate projected traffic volume.

A new, signalized pedestrian crossing would be required to provide safe access across the new five lanes, but traffic analyses also demonstrated that a new signalized intersection would significantly inhibit both pedestrian crossing <u>and</u> highway vehicular movements.

Towamencin Township commissioned design/engineering studies to convince its partner, the Pennsylvania Department of Transportation (PennDOT) of the advantages to depressing Forty Foot Road as a means to create a 16.5 foot vertical clearance envelope

for a new grade-separated crossing structure – a pedestrian bridge – over the highway to allow safe pedestrian and bicycle movements between the two halves of a new mixed-use town center district.

The new pedestrian bridge was designed to become the primary link and "spine" of a township-wide trail system within the village, in accordance with the Township's trails master plan. The new village transportation network was planned as multi-modal to encourage walking, biking, transit, and ride-sharing within the revitalized village. A mix of social, residential, office, civic, and commercial services were considered essential components of the new town center to justify and support the transportation investments.

The Towamencin Town Center Plan was implemented by municipal supervisors and supported by several consecutive boards over a 14-year period. The transportation element, including the pedestrian bridge, was completed in 2007 by PennDOT as the construction and funding partner.

The Township sought development proposals for the new town center that would capitalize on the new zoning overlay ordinance and the new transportation infrastructure. The bridge was designed to function for both "pre" and "post" town center development. Land development around the bridge continues today under the zoning ordinances developed as part of the Town Center planning process.

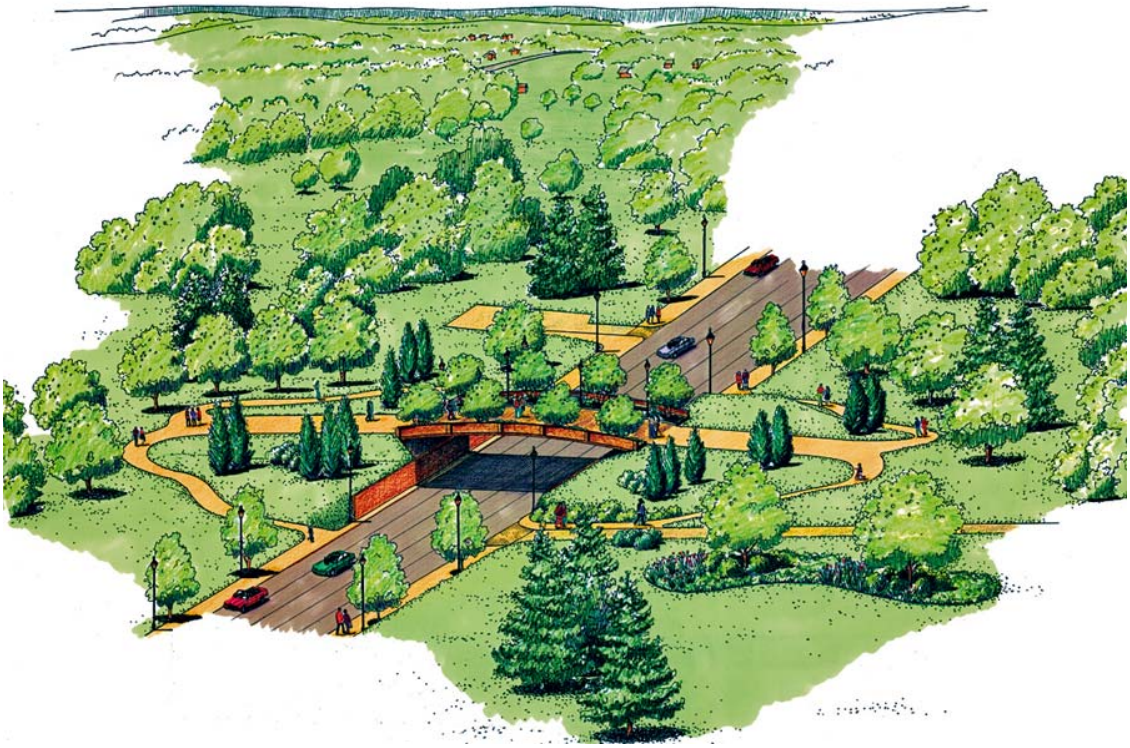


Figure 3 *– Concept design for depressed highway and pedestrian bridge with streetscape amenities and walkway access ramps in Phase 1 – before development of surrounding parcels. The general aesthetic program for the transportation infrastructure was developed in this stage of design.*

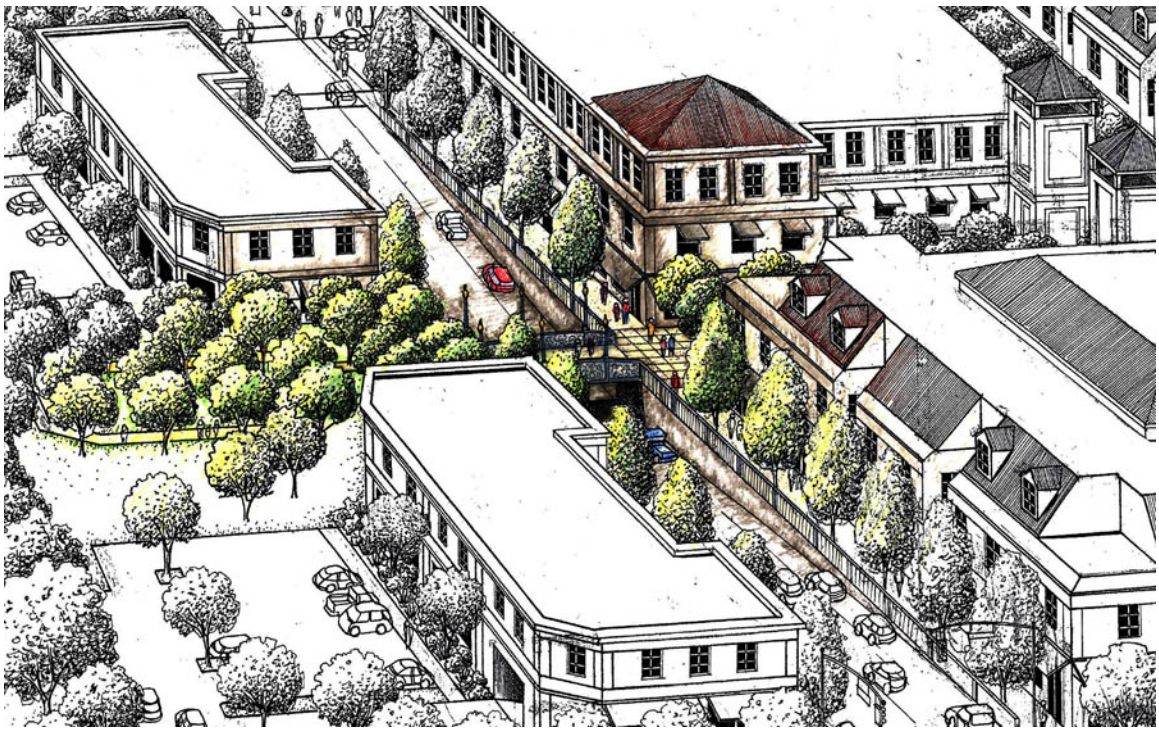


Figure 4 *– Concept design for Phase 2 development of parcels surrounding the depressed highway and pedestrian bridge with streetscape amenities at the level of the bridge deck. The adopted zoning overlay provided incentives for structured parking. The depressed highway alignment has allowed development proposals to utilize the lower roadway elevation for parking access below buildings.*

PROJECT DESCRIPTION

The Forty Foot Road Pedestrian Bridge is the keystone of the Towamencin Town Center plan and integrates municipal goals for parks, open space, trails and greenway systems with streetscape, transportation improvements, and incentives for mixed use development.

The pedestrian bridge and MSE highway retaining walls represent about 10.75% of a $13 Million project that extends roadway improvements for a total length of 8,165 feet.

Major roadway widening and reconstruction, concrete paving installation, bituminous paving overlay, medians, turning lanes, bike lanes, stormwater drainage facilities, utility relocation, lighting, planting, and intersection improvements represent the balance of the project scope. Signalization improvements include five intersections with interconnected fiber optic cable into the township closed loop system.

The combination of these technical achievements delivered a complete modernization program of safety and accessibility improvements within the state highway right of way, with the new context sensitive bridge as the most visible and popular feature.

BRIDGE ALTERNATIVES / SITE SELECTION

The basic bridge geometry and alignment was shaped by typical engineering considerations. Other architectural and humanizing context criteria were considered as early as possible in the design process.

Alignment

The central axis or "spine" of the new town center street grid was originally designed as an "at grade" crossing perpendicular to Route 63. This general alignment also suited the concept for a pedestrian bridge.

Topography

The topography of Route 63 near the proposed pedestrian spine appeared to be conducive to creating a pedestrian bridge that could land on modified grades on either side of the road. The bridge concept was proposed by the landscape architect, and the civil engineer concurred with the potential site suitability. The Township commissioned studies to determine the potential effects and cost/benefit comparison between alternatives of (a) no bridge, (b) a totally depressed alignment, and (c) a partially depressed alignment.

A minimum design clearance of 16.5 feet from roadway surface to bottom of structure was used to assess the alignments. Alternative highway gradients to create the depressed roadway were analyzed in terms of design speeds, sight distances, views, and maintenance of adjacent local access to the state highway.

Stormwater

Any new depressed roadway design required a stormwater low point to be set to allow gravity drainage to a detention facility within the town center project area. Potential effects of new land use development in the quadrants around the pedestrian spine were also assessed and included in the engineering of a stormwater piping system – sized to serve a future centralized facility that will accommodate high density development within the town center district.

Signalization

The engineering analyses considered the capital and operation costs of new Forty Foot Road traffic signal required by the surface crossing alternative. It was recognized that if highway traffic was not forced to make an additional stop at a new signalized pedestrian crossing, cost savings would be realized in terms of reduced travel times, energy consumption, and pollution.

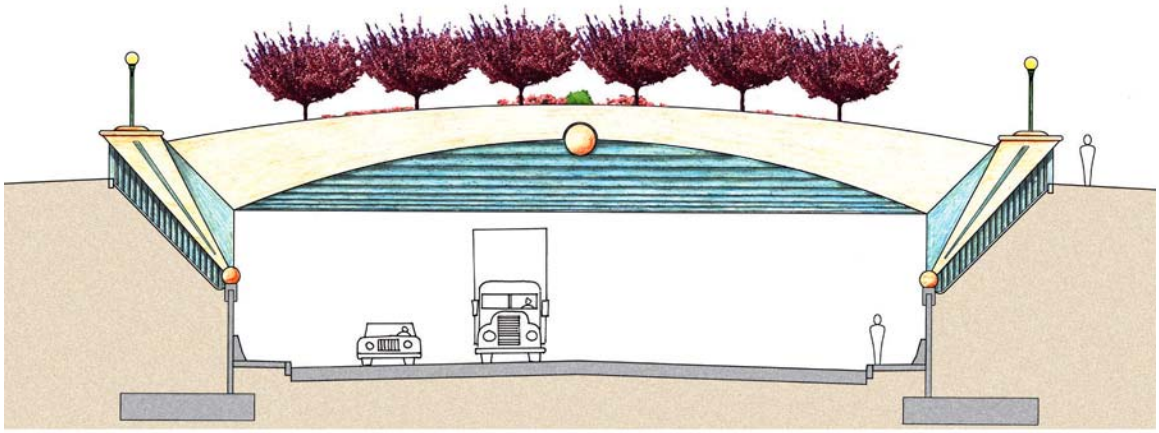
Adjacent Land Use

The bridge symbolizes the commitment to the multi-phased plan by Towamencin for economic development within the Town Center. The bridge and pedestrian approaches are integrated within the highway geometry modifications to achieve optimum mobility in the near and long term, and are; universally accessible, a visual attraction, and catalyst for adjacent redevelopment. The bridge deck was conceived to serve as a civic plaza space after adjacent private development occurs.

Preferred Alternative

A partially depressed alignment was selected as the preferred alternative, based upon balanced grading, roadway and pedestrian approach gradients, aesthetics, and costs. The studies were submitted to PennDOT as the basis of negotiation by the Township. A successful case was made that the bridge would be safer and more efficient than a new surface crossing on Forty Foot Road.

BRIDGE DESIGN



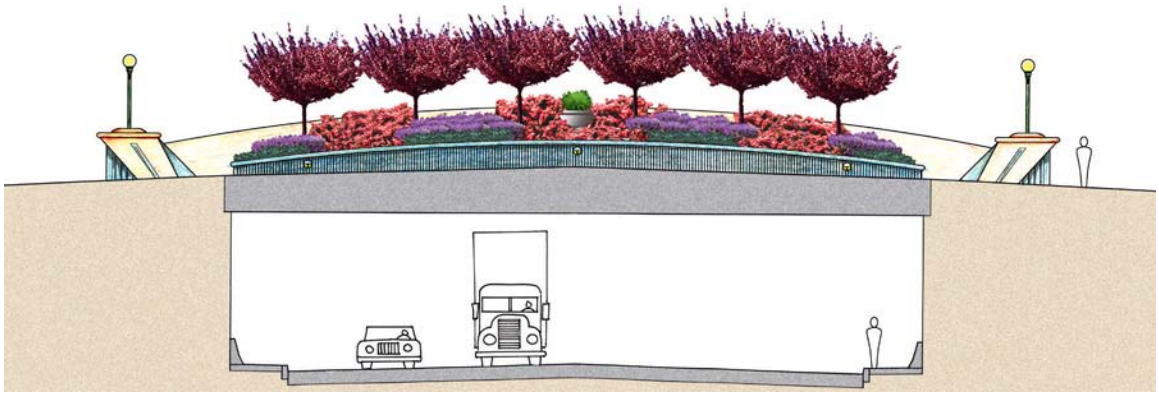


Figure 5 *– In this case the highway bridge becomes a "landscape" structure and features Art Deco detailing in concrete surfaces (above) elevation shows fascia beam and pylon ornamentation; (below) longitudinal section through center of deck shows built-in concrete landscape planters.*

Intent

Towamencin Township envisioned the new pedestrian bridge to be more than a simple pedestrian conduit over a busy highway. Expectations for the bridge included; high level of aesthetics, durability of materials, low maintenance, and multi-functional uses.
The wider bridge design "reclaims" some land taken by the highway expansion.
The new span also sets the standard for scale and service of the new town center streetscape. The bridge itself is designed as a civic "place," both inviting and a landmark for motorists and pedestrians. Architectural features were designed to evoke the best tradition of historic parkway bridge design using modern techniques.

Geometry

The geometry of the bridge is visually deceptive. The clear span from center to center of bearings is 78'-6"over five traffic lanes, shoulders, and sidewalks on both sides of Route 63. The primary "fascia" beams are structural members up to 12 feet deep and 90 feet long, designed with integrally formed architectural features. The bridge is 40 feet total width with curving planters built into both sides of the deck to create a sweeping, variable-width promenade. The deck is for pedestrian and bicycle traffic only, however, the bridge is engineered to support an H20 truck load to serve maintenance and emergency vehicles.

Approach Grading

The site was sculpted to depress the state highway and to elevate the bridge structure. A subtle 3% gradient for both Route 63 approaches was designed by the civil engineers to allow complete visibility under and through the bridge to the town center landscape on either side. This feature eliminates any "tunnel" effect for roadway traffic. The pedestrian approaches are designed to meet ADA regulations from all quadrants.

Retaining Walls

Four, 85-foot long MSE retaining walls were designed by the geotechnical engineer to create the grade separation along the depressed Forty Foot Road. The MSE walls employ standard precast concrete materials and were engineered to support and drain paved, geogrid reinforced sloping walls above.

Pedestrian Environment

The bridge deck was designed as a generous pedestrian environment, cloistered by the fascia parapets from the sights and sounds of highway traffic below. The bridge serves as the "spine" of the Township pedestrian and bicycle network to connect the township-wide trail system to the future town center open spaces. The cartway is wide enough to serve as a "civic" space for periodic functions within the town center. Built-in planting beds establish a human scale and sensual amenity. Pedestrian lighting was designed for safety and ambiance.

Construction Considerations

To prepare for the Forty Foot Road / Bridge construction project, Towmencin Township designed and built a municipal road around the project area as a bypass to maintain state highway and Turnpike-bound traffic. With Forty Foot Road reopened and adjacent land redevelopment beginning, the bypass road will be re-striped to become "Towamencin Avenue," a town center street with on-street parking. This early investment in infrastructure allowed Forty Foot Road to be closed for roadway excavation and bridge construction with reduced traffic maintenance costs, and created a valuable new asset for motorists and local developers.

The structural engineer assessed the options for constructing the large fascia beams, including construction of the beams in place (standing and flat) and precast / delivered. All options were determined to be technically feasible. Ultimately, prefabricators did not respond to the project due to issues of transporting the fascia beams. The prime contractor elected to build the beams in place, with formwork set on scaffolding bearing on the asphalt sub-course of Forty Foot Road.

Figure 6 *– Forty Foot Road was excavated and utilities relocated. The contractor elected to build the roadway base course and erect scaffolding to support structural formwork for the fascia beams. The fascia beams were designed with haunches to bear the outer edges of the deck. Three interior stringer beams support a traditional structural concrete deck. Computer-cut foam art forms were used inside the structural forms to create the fascia art motif. Structural pylons were clad with formed concrete art panels.*

INTEGRATING AESTHETICS AND ENGINEERING DETAILS

Aesthetic Design Process

Determining the "context" and selecting the art features of the bridge was a rational design process that was fully integrated with engineering from the project conception.

Philosophy

The aesthetics of Forty Foot Pedestrian Bridge exceed the minimalist sensibility of beauty inherent in "pure" structural solutions. In this case, the added "architecture" creates a restrained aesthetic for the structure by evoking the archetypal language of engineering geometry.

Art lines are designed as graphic interpretations of forces active within the bridge, including tension, compression, camber, bearing, and repose. These symbolic acknowledgements respect real structural features such as corbels, spring points, hinges, and keystones. Scale was carefully considered to integrate structural requirements with visually pleasing proportions. The result is a subliminal sense of harmony and balance to the structure.

Fascia Beams as a "Canvas"

The fascia beams were selected as the primary members for art treatment for their visibility. A conventional concrete bridge design for this span would not normally provide the opportunity to create such a large uninterrupted canvas for art forms. Typically, a solid parapet would be created by either fastening a jersey barrier, cast in place wall, or precast sound barrier to a composite concrete box beam superstructure / concrete deck. In some cases, art treatments are applied to these vertical elements, but rarely does artwork affect their shapes, engineering, or construction methods. The challenge to the structural engineer was to create an uninterrupted full-span, full-height beam that could be constructed practically.

Engineering Innovation – Fascia Beams

The structural engineer created a hybrid beam member that acts as a standard load-bearing concrete stringer beam with geometry modified to include the safety functions of concrete parapets as well as the sound-dampening functions of sound walls within the new concrete fascia beam design.

The success of the aesthetic ideas for the fascia beams relied on this engineering innovation – not only to provide the venue for the proposed artwork, but to become the true artistic achievement. The art motif responded to the bold engineering in the form of elegant, sweeping arch lines and Art Deco-style detailing within the deceptively massive 80-foot span fascia beams.

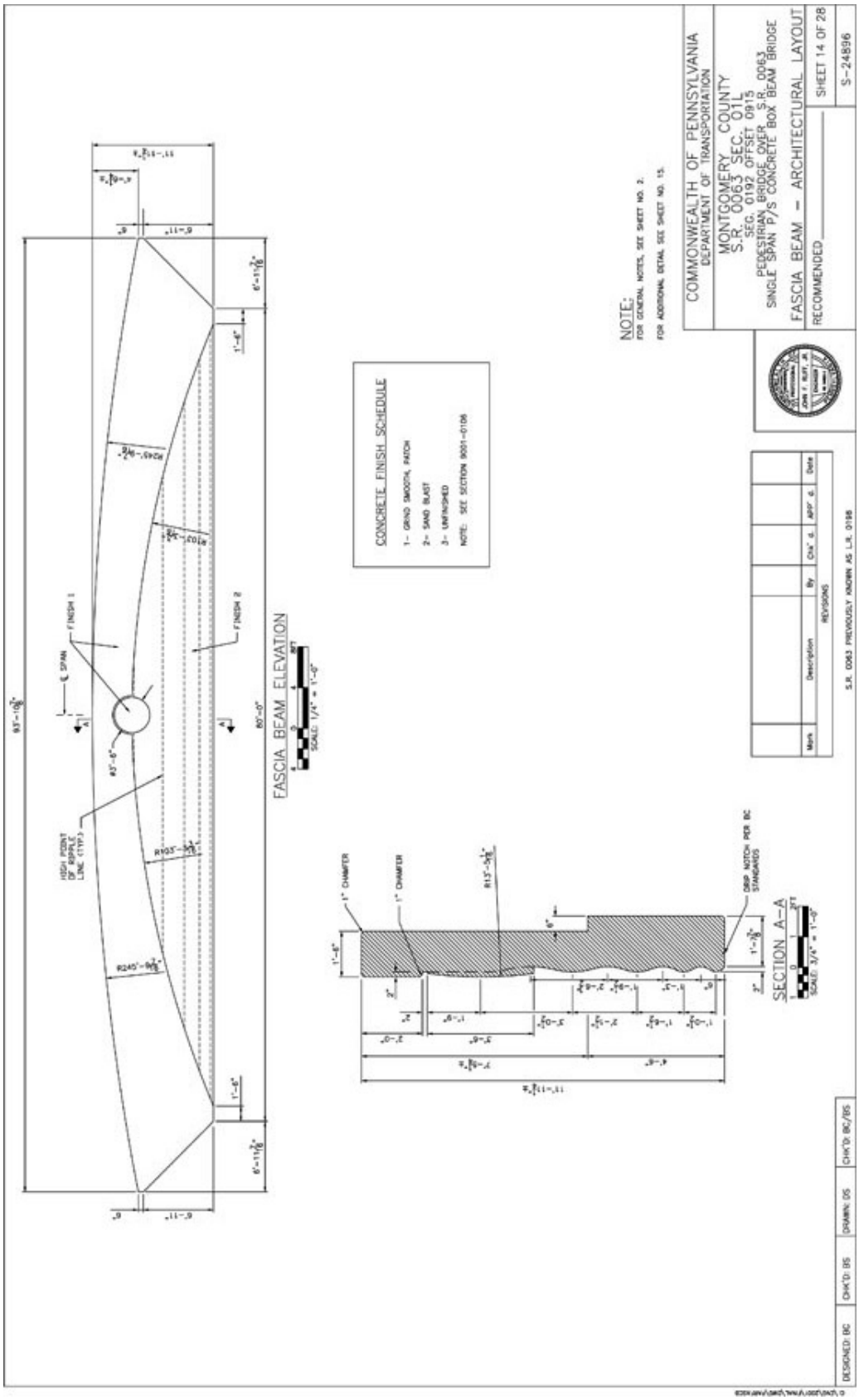


Figure 7 *– Landscape architect's construction document for fascia beam architectural treatment.*

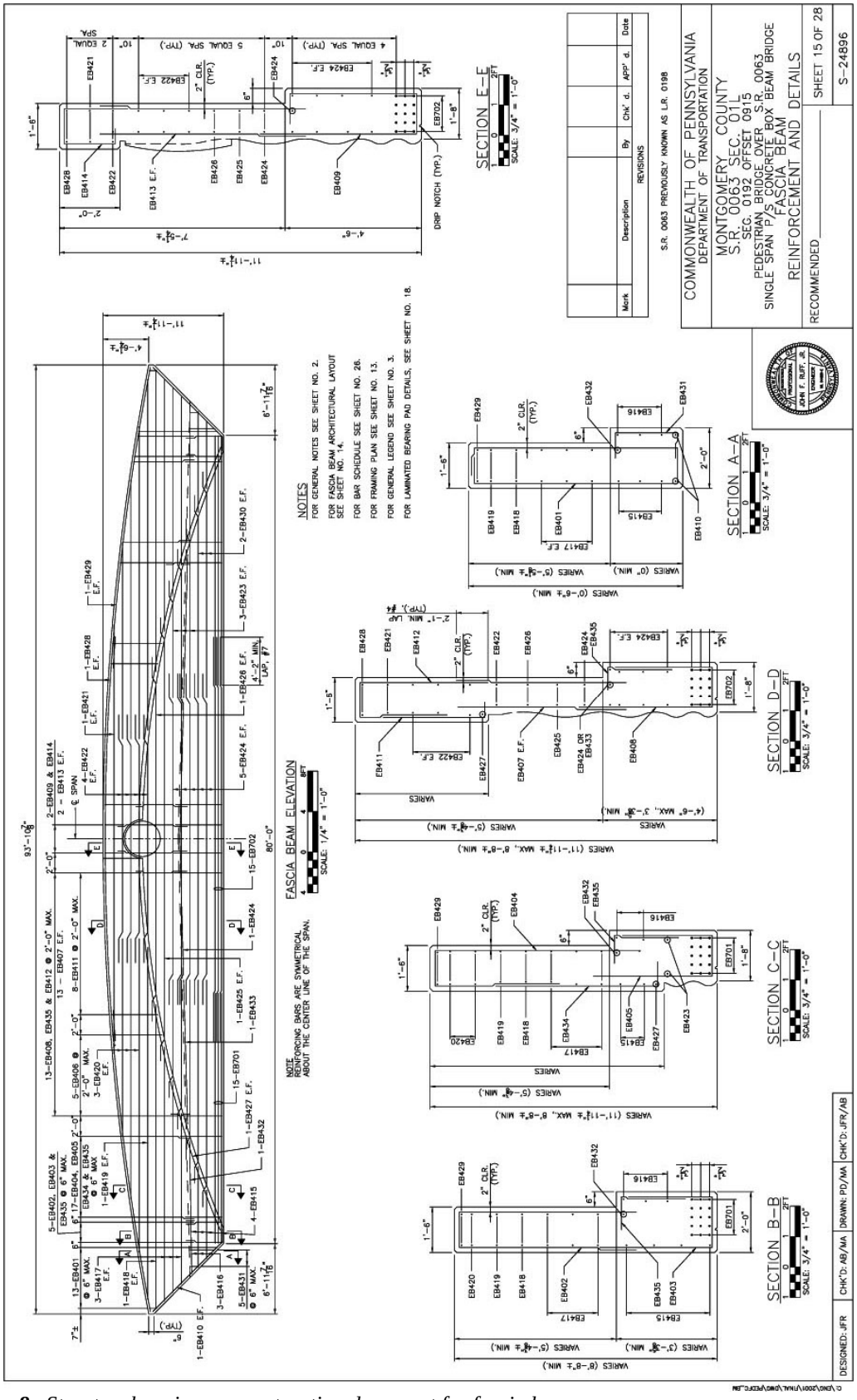


Figure 8 *–Structural engineers construction document for fascia beam..*

The fascia beams extend above the deck elevation to create the appearance of a rigid frame. The structural concrete deck bears on interior haunches of both fascia beams and three interior box beam stringers. This design allows deck edges to be hidden, with only the structural wearing surface exposed and treated. Concrete buttresses hidden within the planters tie the beams structurally to the deck.

The fascia beams are simple span reinforced concrete members designed to seat on cast in place concrete abutments with standard laminated neoprene bearing pads. Within each fascia, 15 epoxy-coated #7 bars provide the primary flexural reinforcement, and epoxy-coated #4 stirrups act as shear reinforcement. Both ends of the beams slope up behind the abutments to cantilever toward structural pylons that are supported on the substructure.

The curved top of the fascia beams was an aesthetic decision that the engineering accommodated to soften the shape and "reduce" the visual mass of the member. The curves at the top of the beams become part of the visual arch created by the art line formed below into the face of the fascia beam.

Art / Architecture Forms

The architectural design of the bridge exploits the versatile, plastic nature of concrete and employs a combination of treatments to the material.

The formed arch line and the shadowed relief that it creates in the fascia beams was designed to "lighten" the apparent mass of bridge structure. CAD-generated, computer controlled and cut styrene form liners were used to create the art features within the fascia beams. The art relief below the arch was designed to be simple and intriguing ripple forms that change frequency and capture the general fluid nature of movements below a bridge. The horizontal shadow lines created by the ripples were designed to subtly elongate the bridge and "de-emphasize" the sense of its vertical dimension. Maximum depth of relief in the structural beam is four inches.

Sloped Paver Walls

The most important architectural decision after the fascia beams was the engineering of the sloped paver walls, above the MSE retaining walls. The sloped walls were designed using geogrid-reinforced slopes at a 1:1 gradient to expand the sense of openness and provide visual relief from the roadway vantage point. The sloped walls allow the roadway environment to open up to light and views toward the pedestrian streetscape environment above, and are visible from all directions.

Without the sloped walls, the MSE retaining walls would have been much higher, and the roadway approaches to the bridge would have appeared much deeper and narrower. This would have created a severe "trough" effect in the roadway environment, and the bridge would have appeared shorter and higher.

Figure 9 *– The sloped walls above the MSE retaining walls reduced the sense of depth of the roadway and were constructed with standard concrete unit pavers and stabilized with geogrid reinforcement. The pavers were finished with dark mortar and urethane anti-graffiti treatment.*

The sloped walls allow the engineered abutment wing walls to be visible as they extend away from the bridge portals and to serve as "pylon" elements. The cantilevered ends of the beams slope up from the abutments to the structural pylons and are clad with architectural wing wall façade panels attached to the structural pylon cores. The sloped wall allows the formed arch in the fascia beams to appear to "thrust" from the 45-degree angle bearing line.

The material selected for treatment of the slopes was very important. The maintenance program eliminated the option to vegetate the steep 1:1 slopes. Conventional concrete unit "brick" pavers were specified on sloped concrete slabs and laid on a mortar bed in a fan pattern. The paver walls were designed and installed as compressive structures, bearing against the MSE walls and tied to grade using geogrid reinforcement. These reinforced slopes are reportedly the first to be designed and constructed using geogrid reinforcement within PennDOT District 6-0. A trench drain was engineered behind the cap of each quadrant of MSE wall to drain the sloped walls. Dark mortar was used in the paver joints to reduce contrast and the finished sloped surfaces were treated with a transparent urethane sealant.

The sloped walls will remain structurally intact, even as development occurs in the quadrants around the bridge. A new hotel complex in one quadrant uses the new building foundation to re-anchor MSE reinforcing ties.

MSE Retaining Walls

Precast MSE panels with vertical rustications were selected from in-stock materials as the most economical option for roadway retaining walls. At the deepest point, the MSE walls are exposed eight feet. The art design takes advantage of the line of MSE wall caps as an architectural corbelling feature by adding custom cast finials where MSE walls meet the abutments.

Abutments

The abutments are conventional cast-in-place, reinforced concrete with in-stock architectural rustication formwork to match the MSE wall panel rustications for visual continuity. Structural abutment wing walls support custom, precast concrete architectural panels that are used to unite the fascia beams visually to the pylons. Precast wing wall caps sit down over the architectural panels and support finial globe lights on each pylon.

Deck

The deck is 40 feet wide at the portals and narrows to 20 feet wide at center span between the cast-in-place landscape planters. The deck slopes away from midspan at 2% to direct water to trench drains at either abutment and to reinforce a subtle, ceremonial “camber.” Concrete deck material was extended in semicircular aprons outside each portal to create a graceful approach and sense of spatial transition to the bridge.

A dark red aggregate was specified for the deck mix with an analogous red stain in the urethane surface coating to provide contrast to the lighter colors of the other bridge elements. The deck aggregate was exposed and a three-foot apron at the base of both planters was stamped to impress a fan pattern to match the sloped wall pattern. Both texture treatments were used specifically to inhibit the attractiveness of skate boarding on the desk. A construction achievement was creating the stamped patterns in the same deck using retardants to achieve an exposed aggregate texture finish for the primary walk area.

Figure 10 *– The portal elevation of the bridge reveals the sweeping forms of the concrete landscape planters that echo the curves of the fascia beams and deck. The planters are insulated, waterproofed for drainage and automatic irrigation. Plant material was selected for harsh microclimate extremes.*

Landscape Planters on Deck

The concrete planters formed into both sides of the deck are amenities that capture the elements of the surrounding landscape to temper the bridge deck environment. The size of the planters was designed to create vessels large enough to support medium-sized canopy trees and balance the need for a generous pedestrian cartway. The curved shapes reinforce the curving parapet shape of fascia beams. Planter wall rustications match the scalloped formwork in the wing wall panels.

The planters are insulated, membrane-lined, automatically irrigated, and plumbed for drainage – to create the most optimum growing environment possible. The trees and the insides of the fascia beams are up-lighted from within the planters for night effects. A custom planting soil medium was designed for optimum growing culture in harsh conditions. Hardy plant materials were selected to meet extreme wind, cold and heat conditions.

CONCRETE MATERIALS / TECHNIQUES / TREATMENTS

Material

Concrete was selected as the most practical and economical material for a bridge of this size and configuration. The entire bridge project is constructed of concrete, using many standard construction items to display a wide range of capabilities in mixing, forming, and treating concrete material for aesthetics – without any attempt to mimic other materials such as faux stonework.

Combination of Precast and Cast in Place Elements

The bridge design combines multiple fabrication techniques to take advantage of the wide variety of unique properties achievable with conventional precast, custom precast, and custom cast-in-place members, such as;

- conventional precast elements including: prestressed concrete box beams, MSE wall panels/caps, jersey barriers, and conventional sloped wall concrete unit pavers.
- custom precast elements including: pylon wing wall panels, pylon caps, and MSE Wall cap finials.
- cast-in-place elements including: reinforced concrete fascia beams with custom prefabricated architectural form liners, reinforced concrete abutments with architectural treatments, bridge deck, curved planter walls, and coping on deck.

A White Portland cement mix was specified for all cast-in-place structures and architectural elements to show off the colors of exposed aggregates and to provide the most pure concrete base for translucent color staining. This proved to be effective for treatment of the exposed aggregate areas of the planter walls, wing wall panels and fascia beams, where a lightly pigmented urethane coating allowed the white Portland cement mix to show off the selected color. This was not the case where the urethane treatment was applied without pigment and the bright white color of the raw concrete was darkened and uneven using a clear urethane. The remedy was to pigment the urethane treatment of exposed aggregate areas with translucent color and all other areas with opaque color.

Three classes of concrete were specified for the bridge. Class A (f'c=3000 psi) was used in the foundations, abutments, and wingwalls. Class AA (f'c=3500 psi) was used in the fascia beams, wingwall panels, and planter wall. Class AAA (f'c=4000 psi) was used in the reinforced concrete deck slab.

The superstructure also contains three standard prestressed concrete box beams. These 48" wide by 36" deep beams were fabricated using concrete with a 28-day strength of 7000 psi. The beams contain 50, 270 ksi low relax strands, 12 of which are debonded for 12 feet at each end. The beams were prestressed with an initial jacking load of 1691 kips.

Techniques

Architectural techniques employed include:

- sandblasting – to expose aggregates for aesthetics in specific surfaces in the fascia beams, wing wall panels, and planter walls. The contractor chose grinding and wire brushing for certain surfaces.
- retardant – to expose ornamental aggregate in the deck for aesthetics and non-slip texture. The contractor found the challenge was to use retardant in the mix to expose aggregate while stamping the surface of the same concrete pour without exposing the aggregate.
- Stamped concrete – to create architectural patterns in the concrete deck to match the patterns of the pavers laid for the sloped walls.
- form liners – custom-cut form liners fabricated using an automated shaping machine programmed to read the AutoCAD construction documents and to create precisely matched panels for the ripple forms in the fascia beams.
- water-resistance admixture – for deck and fascia beams concrete mixes, to improve water resistance of high-cost primary members where de-icing salts threatened longevity. This was considered a prudent investment with the fascia beams tied to the deck with structural buttresses and the steel of architectural concrete planter walls tied to the deck.

Concrete Treatments

A custom-colored, aliphatic urethane treatment was applied to all exposed surfaces of the bridge and retaining walls.

Color

Color for the concrete surfaces was specified extremely carefully to allow for multiple field mockups and photo-rendering studies of the actual structure during construction. Early concepts using several colors were simplified to two colors and a bright white.

The deck was stained a medium burnt red with dark red aggregate to reduce glare. A light sea green was selected as the translucent color to be applied to the exposed aggregate areas. The color hue and value were balanced to accent the rougher exposed aggregate textures and strategically set off the opaque bright white to emphasize specific art shapes.

In the case of the fascia beams, the light green is used below the arch shape to make the ripple forms visually “recede” and push the white arch forward. The effect from a distance is that the green tends to blend with the sky and landscape colors and the slender arch leaps across the road ahead.

COSTS / FINANCING

CONTRACT AMOUNT, PROJECT SCHEDULE, AND STATISITICS

The project was documented and bid using the standard PennDOT Electronic Contract Management System process and awarded to the lowest qualified bidder. The original and final contract award amount was $12,976,706.50, bid by Road Con, Inc. The project let date was September 9, 2004, and construction started in December 2004.

The Bridge was a lump sum cost of $1,039,845 (including rebar). The MSE walls were also lump sum items at $77,000 each ($308,000 for all four).

The project was constructed in five stages and several were built concurrently. Towamencin Avenue was built in 2001, as part of the Towamencin Township Village Plan and in advance of this project, to create a convenient detour for Forty Foot Road. Forty Foot Road excavation depressed the finished roadway elevation 8 feet to construct the pedestrian bridge and MSE walls. This plan also allowed for full width reconstruction with no maintenance of traffic on Forty Foot Road. Forty Foot Road was reopened to traffic in December 2006. Time extensions were granted to extend the construction schedule into June 2007 to complete the pedestrian bridge. A technical time extension was granted until spring 2008 to allow for final inspection/installation of the plantings, testing and municipal training for bridge maintenance.

PARTNERSHIP FINANCING

The project was structured as a local match between the Towamencin Township Infrastructure Authority (TTIA) and PennDOT. The TTIA was responsible for 100% of the engineering costs and PennDOT was responsible for 100% of the construction costs – using a typical 80% federal to 20% state matching ratio. The project was conducted as a phased process, with the municipality commissioning all planning, design, and engineering costs. Ownership was a structured as “turnkey” agreement, where the Township assumes ownership and maintenance of the bridge upon completion.

LIFE CYCLE INVESTMENTS

Higher capital costs were found to be acceptable for value-added features, materials, and techniques that were considered as smart life-cycle investments to reduce maintenance costs. Adding the water resistance admixture to major structural elements including the fascia beams and deck was considered prudent by the Township as the “turnkey” owner that would assume maintenance. PennDOT considered this investment prudent as part of the terms of ownership transfer that would remove the bridge from the state highway system in perpetuity.

Higher capital costs for context design features were found to be acceptable as a catalyst for local private investments to increase tax ratables to contribute as a perpetual source of bridge maintenance funding to the Township..

SUSTAINABILITY

The pedestrian bridge was conceived in 1994, on the early edge of investments in "green infrastructure." The merits of the bridge were considered in terms of energy and environmental savings as well as pedestrian and vehicular safety issues of a grade-separated crossing of Route 63. Sustainability considerations for the bridge included the following features:

- Walking Alternative – The new pedestrian bridge offers an inviting and convenient alternative to driving across the road, an option that significantly reduces costly fuel consumption, greenhouse gas emissions, and air quality pollutants generated from inefficient and dirty vehicular "cold starts" to otherwise drive across the road.

- Vehicular Efficiency – The new pedestrian bridge eliminates an additional traffic signal for a pedestrian crossing on Route 63, making it a green infrastructure capital investment that significantly reduces inefficient fuel consumption by eliminating the need for hundreds of dead stops, idling, and acceleration of highway vehicles daily within the town center. This is a major contribution to regional air quality and fuel efficiency for all citizens.

CONCLUSION

The Forty Foot Bridge project demonstrates how proactive land use planning by a small, but determined municipality can positively impact transportation infrastructure decisions.

Depressing an existing state highway alignment to accommodate a new pedestrian bridge is a rare achievement between PennDOT and local governments and reflects the growing emphasis within the Department toward creating highly functional, multi-modal context sensitive improvements.

Within the Towamencin Town Center, the new bridge serves as an icon and catalyst for future mixed-use, pedestrian-oriented development in adjacent parcels.

The successful execution of this bridge within the standard PennDOT procurement process demonstrates that there is the sufficiently high level of craftwork capability in the marketplace to construct such custom design and technically challenging projects.

The Forty Foot Pedestrian Bridge is a visible landmark and benchmark for excellence in the design of public infrastructure.

AWARDS

The Forty Foot Road Pedestrian Bridge and Roadway Improvement project received the

- *2007 Project of the Year Award* from the American Society of Highway Engineers (ASHE) Delaware Valley Chapter - for projects over $5 million.

The Forty Foot Bridge was acknowledged to receive the

- *2008 PCA Bridge Design of Excellence Award* from the Portland Concrete Association – to be presented on November 2, 2008.

The *Towamencin Town Center Plan* won three planning awards in 1996.

ACKNOWLEDGMENTS

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Concrete blocks were cut apart for examination of the duct coupler where installation procedures were tested in this mock-up of a precast segmental joint. Photo: Mn/DOT.

The void area around the duct coupler raised concerns where chlorides could potentially collect in the top slab. The duct couplers were tested, but not used within any of the Crosstown segmental bridges. Photo: Mn/DOT.

Photo: Mn/DOT.

Precast segmental construction offered the most advantages and was the most attractive option.

Short-term closures occurred at night to allow for safe erection over traveled ways. Photos: © FIGG.

Photo: Mn/DOT.

A modified AASHTO/PCI/ASBI Section 8-2 was selected for all six segmental bridges

Photo: Mn/DOT.

Aesthetic Design Considerations

A total of 27 bridges were required for the project. These include a mix of bridge types, each serving a unique purpose. Of the total, 12 were precast, prestressed concrete girder bridges and six were precast concrete segmental bridges, five were steel beam bridges, one was a pedestrian steel truss bridge and three were temporary bridges. Compared with conventional construction, segmental structures have a relatively small footprint that allows for a radial placement of the substructures while allowing room to fit traffic lanes between the radial supports. The final plans were developed using an overall aesthetic design guide that reflects the desired architectural theme of the community and provides a uniform visual experience throughout the reconstructed corridor.

Pier shapes and other substructure components such as pilasters were also standardized. Split forms allowed the use of identical curved formwork on the tops of the fluted pier columns. To address variable slopes, the tops of pier caps were set to the nearest slope of 0%, 2%, 4%, or 6% with any additional variation taken up in the bridge seats. This allowed for repeatable use of side forms even with the variation in the superelevation transitions within the bridges.

The project also includes extensive use of precast wall components including precast mechanically-stabilized earth (MSE) wall panels and precast posts for noise walls. Details were also developed to standardize the connections between precast wall panels and the cast-in-place walls at the ends of the bridge abutments.

Aesthetics were considered in all aspects of the project through the use of a design guide that incorporated architectural themes. **Photos: Mn/DOT.**

Simple pier shapes, repetitive in nature, minimize the footprint of the bridge and reduce congestion in a complex construction zone. **Photo: Mn/DOT.**

CROSSTOWN SEGMENTAL DESIGN STANDARDS

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ABSTRACT

The Crosstown Project near Minneapolis, Minnesota is employing precast, segmental concrete construction for the first time in the state. There are six curved ramps in the project, each with varying geometry. PB was tasked to serve as program manager and develop principal details (Standards) that would work for all six structures.

Standards development focused on modifying the AASHTO/PCI/ASBI standard segments to envelope the demands of the six unique ramps. Bulkhead details were developed to identify the number of shear keys, P.T. bars, and tendon ducts that would be utilized in any scenario. Tendon arrangement, blister details, deviator details and segment dimensions were standardized as well. Project specific design and loading requirements were included in the development process. Standardization provided a basis for the three consultants' bridge design efforts while enabling the use of a common casting machine set.

This paper highlights the results of a consensus building design effort amongst the three design consultants and the owner, MnDOT. It presents the more significant aspects of the development and utilization of the design standards.

Keywords: Precast, Segmental, Post-tensioning, Balanced, Cantilever, ASBI, Standards

INTRODUCTION

Just south of Minneapolis, Minnesota on Interstate 35W is the junction with T.H. 62, an east-west corridor that is currently one of the most congested stretches of interstate in the region. These two thoroughfares meet in a reverse curve junction where traffic is combined for a mile until the routes diverge again. The area is known as the Crosstown Commons and it has become notorious for its consistently high congestion levels. The Minneapolis/St. Paul metro region has seen substantial growth in the suburbs while retaining many of the employment opportunities and major attractions. The unbalanced growth has increased traffic volumes significantly, especially in the Crosstown Commons area. T.H. 62 serves commuters from the rapidly growing southwest suburbs while also providing a direct route to Minneapolis-St. Paul International Airport. I-35W traffic, while serving a vital role to North-South interstate transportation, has primarily seen its volume increased due to commuters from the southern suburbs and business areas, including the Mall of America. The combined effects of suburban sprawl, increased southern business attractions, and airport access have created congestion levels which generate economic losses, decreased safety and commuter frustration.

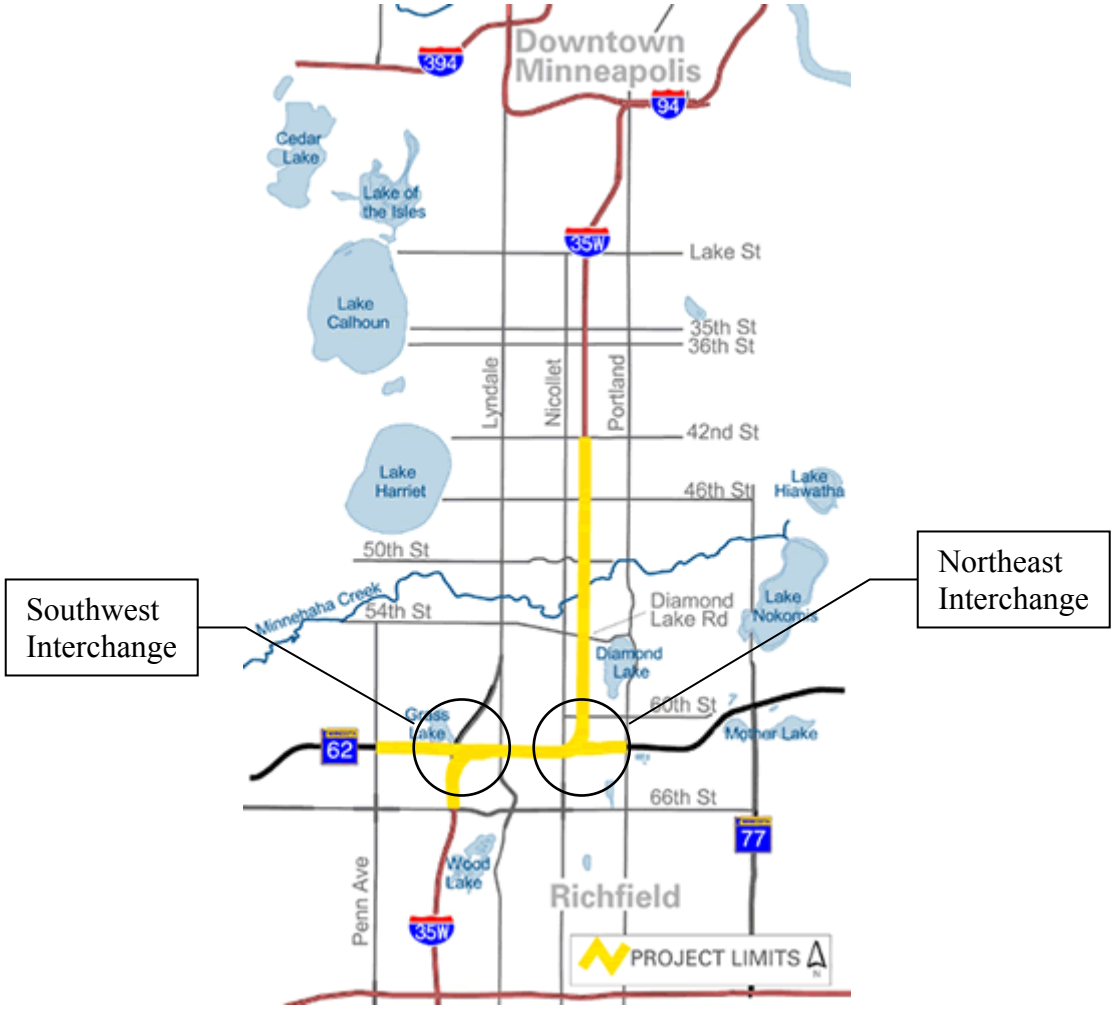


Figure 1: Project Location [1]

The Commons, originally designed in the 1960's, do not meet current traffic requirements. Increasing traffic capacity in the area today is complicated by the fact that the resultant footprint area was minimized in the original design to decrease land acquisition costs. Today's land acquisition costs play an equally important role. In addition, maintenance of traffic during construction has become an increasingly vital consideration. In fact, an early reconstruction plan that would have caused long-term construction closures was rejected because it was deemed unacceptable to a large portion of users and area residents. A new configuration was developed by PB as part of a study to identify options for reducing impacts to the traveling public which proved to be a winning compromise of increased capacity, safety, and traffic maintenance. This concept was then advanced into a type, size & location study by a local transportation consultant. The design called for six flyover ramps, three in each of the interchanges. Preliminary bridge design narrowed the flyover ramp bridge type to that of precast segmental concrete. Two cross-sections were indicated for the ramp superstructure, one for the narrow ramps and another for the wider ramps. The segmental option was chosen for its increased durability, low maintenance, and construction flexibility.

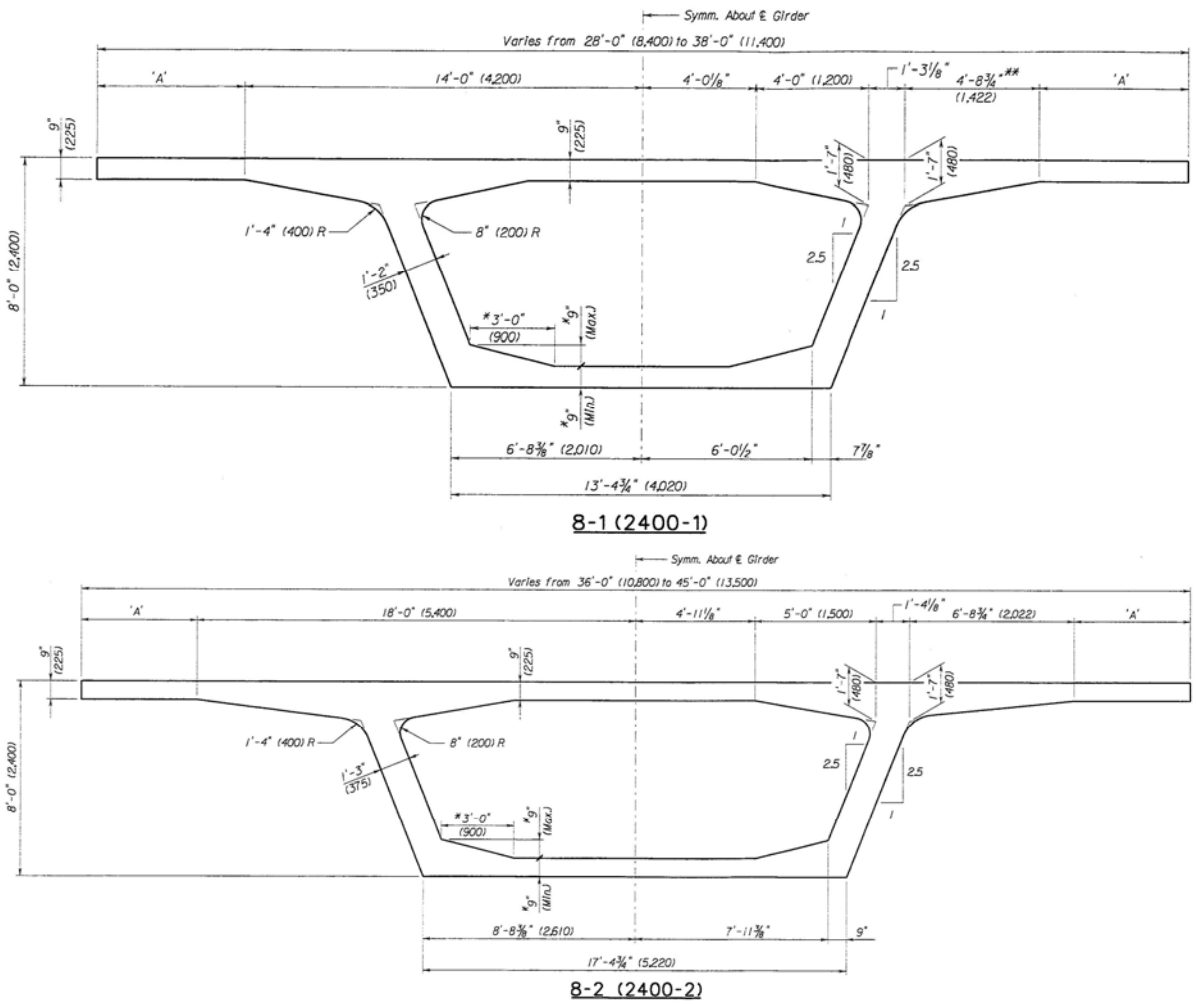


Figure 2: AASHTO Standard 8'-0" deep (2400mm) Segments

Minnesota has used segmental construction on three prior occasions (Plymouth St. Bridge - Minneapolis, Wabasha St. Bridge - St. Paul and Wakota Bridge - Newport), all of which employed cast-in-place segmental construction. However, the six Crosstown Commons bridges will use precast segmental construction for the first time in the state.

PB was one of three consultants[1] awarded bridge design contracts, each being responsible for two bridge designs. MnDOT chose to break the design package out for two reasons – to support multiple local consultants and to increase the comfort level of adopting the new structure type. PB also served as program manager tasked with developing segmental design standards for the six bridges. These standards would serve to fix principal features of the superstructure elements in order to realize savings by maximizing repeatability in the segmental precast construction. As part of the management contract PB also provided training on precast segmental design and construction to MnDOT staff and facilitated design meetings amongst the bridge consultants. PB was also charged with developing design criteria.

The six ramps varied in curvature, width, span range and overall length. Three bridge widths: 45'-4", 43'-4" and 33'-4", were shared by two bridges each. The main span lengths varied from 170 feet to 200 feet with a degree of curvature up to 8.5°+/-. Figures 3 and 4 show the various bridge geometrics. The assumed construction technique for the bridges is balanced cantilever construction. Design was performed using the 2004 AASHTO LRFD Specifications.

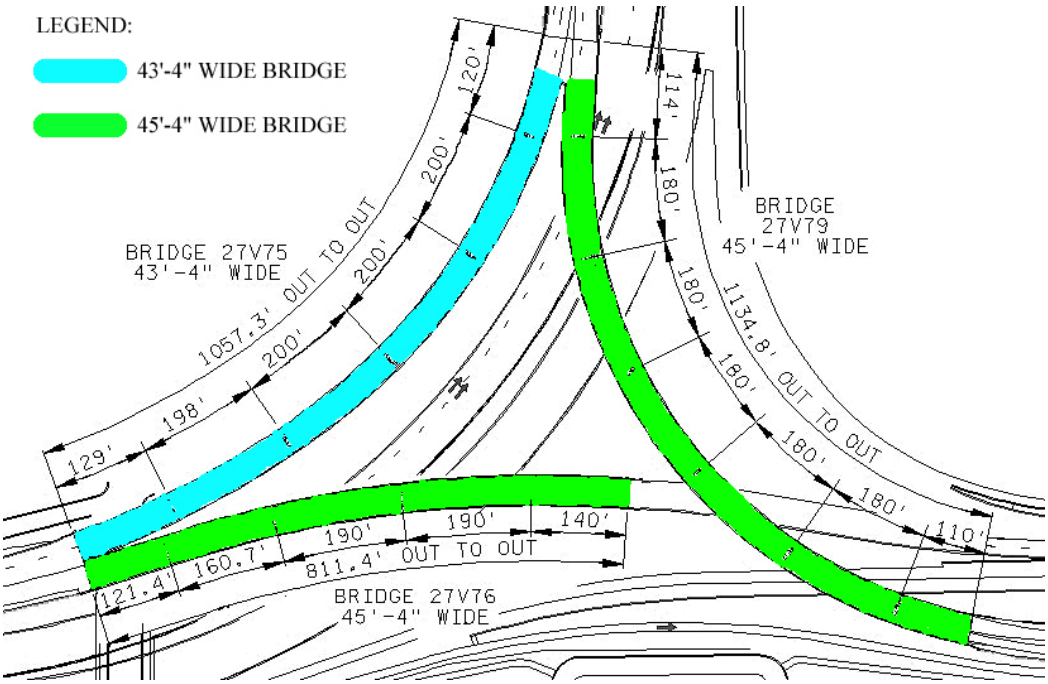


Figure 3: Northeast Interchange of Crosstown Commons

[1] Other bridge design consultants were PTG and URS. SRF served as roadway consultant and reviewed construction staging area requirements.

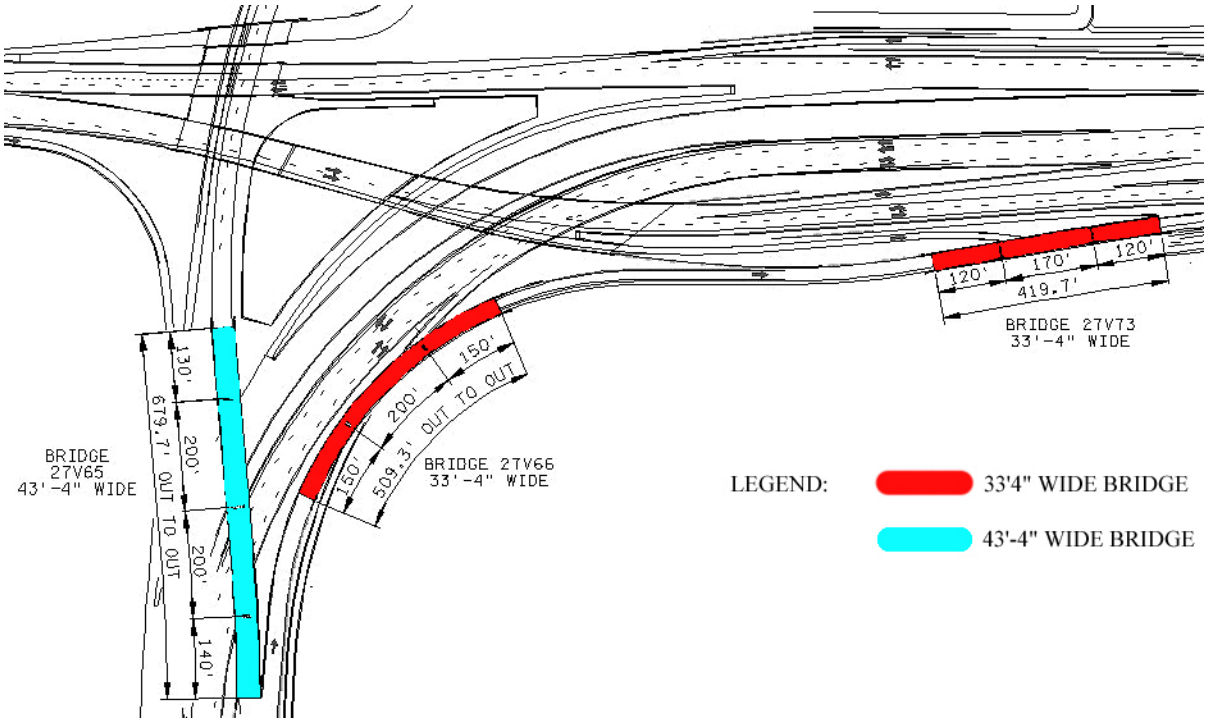


Figure 4: Southwest Interchange of Crosstown Commons

PRECAST SEGMENTAL STANDARDS

The standards developed on the Crosstown project may be grouped into several areas: Segment Shape, Standard Components, Tendon Layout standards, Standard Segment Types, and Transverse P.T. standards. These areas are often inter-related but will be examined separately for clarity.

SEGMENT SHAPE

The segment depth and shape were the first parameters addressed in the design. AASHTO has adopted box girder standards for various construction methods and span ranges. The tight geometric constraints at the site require the choice of the 8'-0" (2400mm) deep AASHTO Standard box girder in lieu of a deeper section. A review of the bridge lengths shows that there are less than 100 of the narrower deck segments, Type 8-1. This relatively low number of segments would make the investment in an additional set of casting forms dedicated to the narrower sections questionable. Studies completed prior to this time were based on the understanding that the project schedule would require 2 sets of forms to produce the segments on the demanding time line. However, for the bridges requiring the smaller cross-section (Type 8-1), such a low number of segments would underutilize the smaller forms. PB considered a special hybrid version of forms that were an intermediate size. In the end, further study showed that the AASHTO Type 8-2 could be modified to work for all

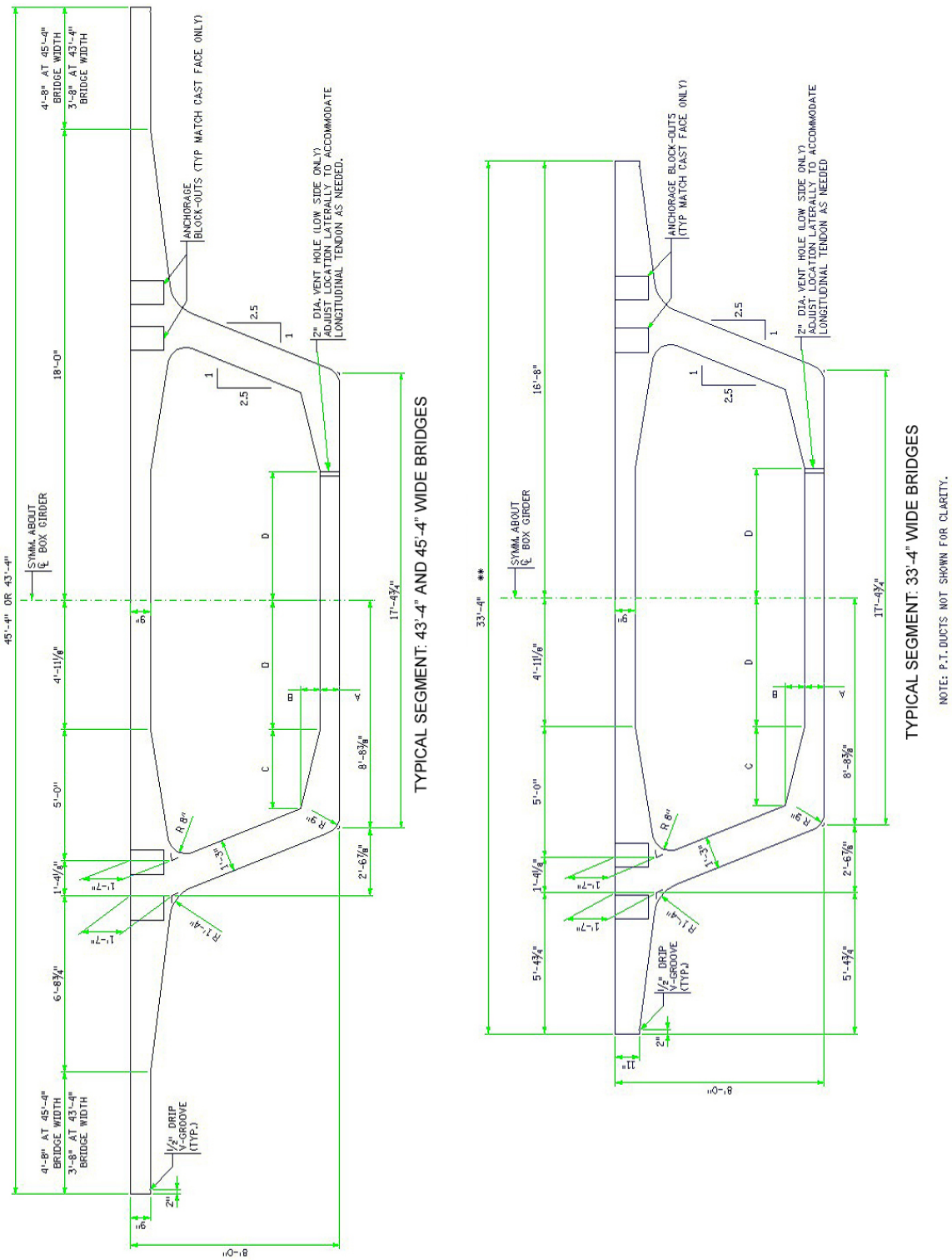


Figure 5: Typical Segment used on Crosstown Bridges.

bridges. Furthermore, use of standard AASHTO forms was desired by MnDOT partially due to potential use of the same forms for other future projects. Use of the wider Type 8-2 would require that the overhanging flanges be adjusted to achieve the varying roadway widths. The wider bottom of the Type 8-2 was a concern because the wider bottom flange combined with superelevation further reduced what was already a tight vertical clearance. In the end, it was decided that the use of just one type, i.e. the Type 8-2, met both economical and geometric considerations. The final typical sections were 10'-0" long and are shown in Figure 5.

The standard box girder shape limits the number of variables by locking in the segment depth, web angle, web thickness and deck thickness. This is important because it increases the economy of segment production by limiting the number of form changes / adjustments that must be utilized. The bottom slab is one location where variances could not be avoided. The bottom slab thickens as it nears the pier supports to accommodate the increased moment demands. The thickness variation is described in Table 1 with accompanying Figure 6. Note that variables "B" through "D" are defined in Figure 5.

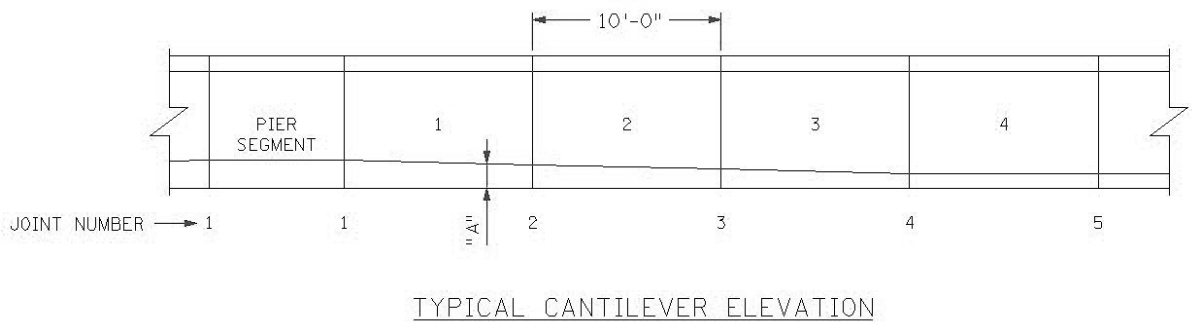


Figure 6: Typical Segment Bottom Slab Variation

TABLE OF VARIABLE DIMENSIONS

JOINT NO.	1	2	3	4	5
DIMENSION "A"	2'-0"	1'-7"	1'-2"	9"	9"
DIMENSIONS "B"	0	0	4"	9"	9"
DIMENSIONS "C"	0	0	1'-4 1/8"	3'-0 3/8"	3'-0 3/8"
DIMENSIONS "D"	8'-2"	8'-0"	6'-7 3/8"	4'-11 1/8"	4'-11 1/8"

Table 1

BULKHEAD DETAILS

Selection of the standard shape is tied to the bulkhead details. The bulkhead is the form used to cast the newest segment face in the construction sequence. It is a form that must

accommodate all the necessary variations that may exist at the interface between segments. Considering this, the definition of the bulkhead details is perhaps one of the most crucial aspects of setting a precast segmental standard. Refer to Figure 7 for the various bulkhead components. The bulkhead for the Crosstown bridges identifies 36 cantilever ducts in the top slab, and 16 bottom or span tendon ducts in the bottom slab. In addition, there are 3 pairs of bar tendon ducts and 5 pairs of continuity tendon ducts. Cantilever and span ducts were sized to accommodate up to 12-0.6" strand and continuity ducts up to 7-0.6" strand.

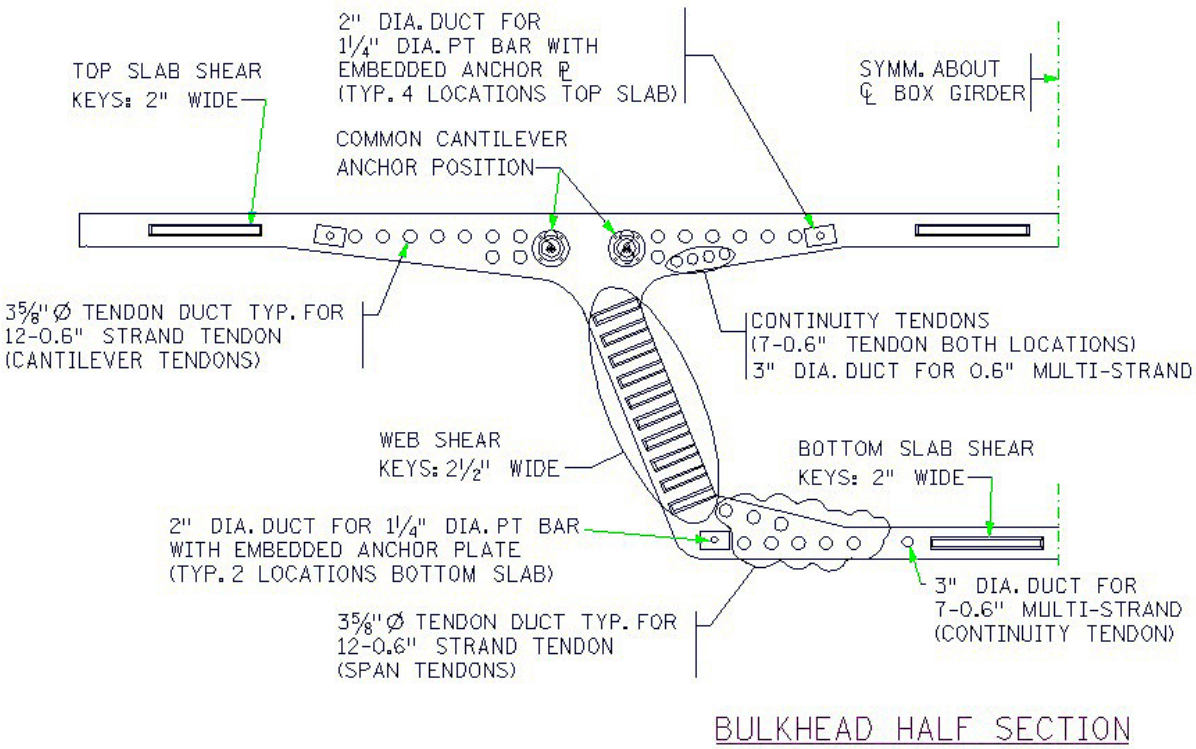


Figure 7: Bulkhead Components

In order to arrive at a common bulkhead design that would work for all six segmental bridges, a preliminary analysis must be conducted for governing aspects of all the bridges in the project. Post-tensioning requirements for segmental bridges constructed by balanced cantilever may be governed by construction requirements or final, in-service requirements. Cantilever tendon post-tensioning is often either governed by construction requirements or the state of stress when the structure is just opened to traffic. Span tendon post-tensioning is usually governed for conditions at time=infinity, when concrete creep has occurred and increased the positive moments between the supports.

Balanced cantilever construction may progress either by lifting the new segment from the ground (by crane) or by hoist and lift, in which case the hoisting equipment creates an additional load at the cantilever. Ground cranes were assumed for the erection of the

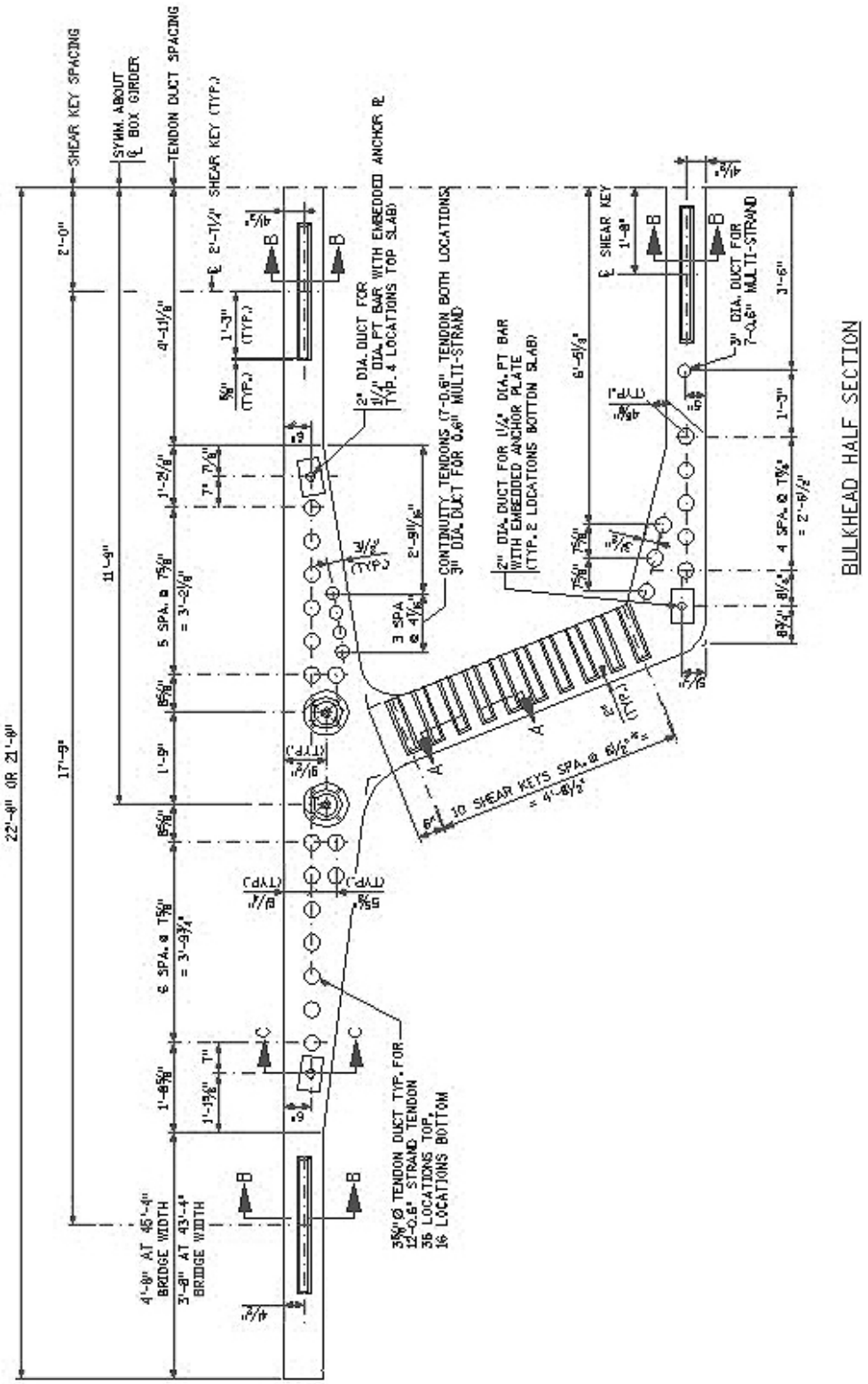


Figure 8: Bulkhead Configuration

segments in the Crosstown project. To satisfy the requirement that there be 5% reserve post-tensioning capacity, it was decided to simply provide 5% more post-tensioning material than the minimum required by design. This was, in general, accomplished by specifying an initial jacking force of $0.86f_{py}$ rather than $0.90f_{py}$. This decision gave the contractor 5% reserve at any segment rather than the provision of a spare duct as enumerated in the AASHTO Specifications.

Six post-tensioning bars are used to compress and expel excess epoxy out of the match-cast joints during erection and to temporarily hold the new segment until the cantilever tendons are installed. Considering the limited space available in the bulkhead, it was decided that these bars should be made permanent and factored into the resistance capacity of the section. This decision also fulfills the desire to minimize the number and size of openings in the deck given the deicing chemicals used in Minnesota.

Span tendons constitute the positive moment resistance once a closure pour is made. For the six segmental bridges, a maximum of 16 span tendon ducts were required. Bridge 27V75 utilized all 16 span tendon ducts, whereas, Bridge 27V66 utilized 10 span tendons, Bridge 27V73 utilized 12 span tendons, and the remaining bridges used a maximum of 14 span tendons.

Continuity tendons cross the closure pour and anchor on the opposing face of the pier or abutment diaphragm. These tendons provide top slab continuity across the closure pour. The bottom slab span tendons serve a similar function as the continuity tendons across the closure pour, and with the exception of a few cases, the bottom continuity tendons were not utilized. The continuity tendons are in place primarily to address thermal stresses and other global forces. A sample tendon layout for one span is shown in Figure 9. The top view shows the girder elevation and the bottom two views show a half-plan of the top and bottom slabs. One can see the top slab tendons drop off as they tend toward mid-span, and the bottom slab or span tendons drop off as one moves away from mid-span. The tendon termination is directly related to the moment and location of tensile demand in the section.

Shear keys are the most basic component of the bulkhead. They serve as a shear transfer mechanism and an aid to the fit-up of segments. In conjunction with the compressive post-tensioning forces across the joints, well distributed shear keys would ensure full transfer of shear forces as if the joint is not there.

Web thickness was governed by either shear strength or principle stress limitations, depending on the structure. Vertical post-tensioned bars have been added in a number of segments near the pier supports to meet the principle tensile stress requirement. The post-tensioned bars are not considered for computing the shear strength of the structure, but rather are considered only for the serviceability requirements of reducing the principal tension in the webs. The alternative of increasing the thickness of the webs was considered but not pursued, because, given the restriction in girder depth, an increase in structural weight would send the design in a spiral of increasing number of tendons, corresponding haunch sizes in

the top slab, and eventually web thickness again. The decision of using post-tensioned bars in the web was agreed upon after confirming that a number of significant bridges, in service for more than 15 years, have shown no sign of problems using the proposed Crosstown details; many of these bridges are in northern states with similar climate-related concerns.

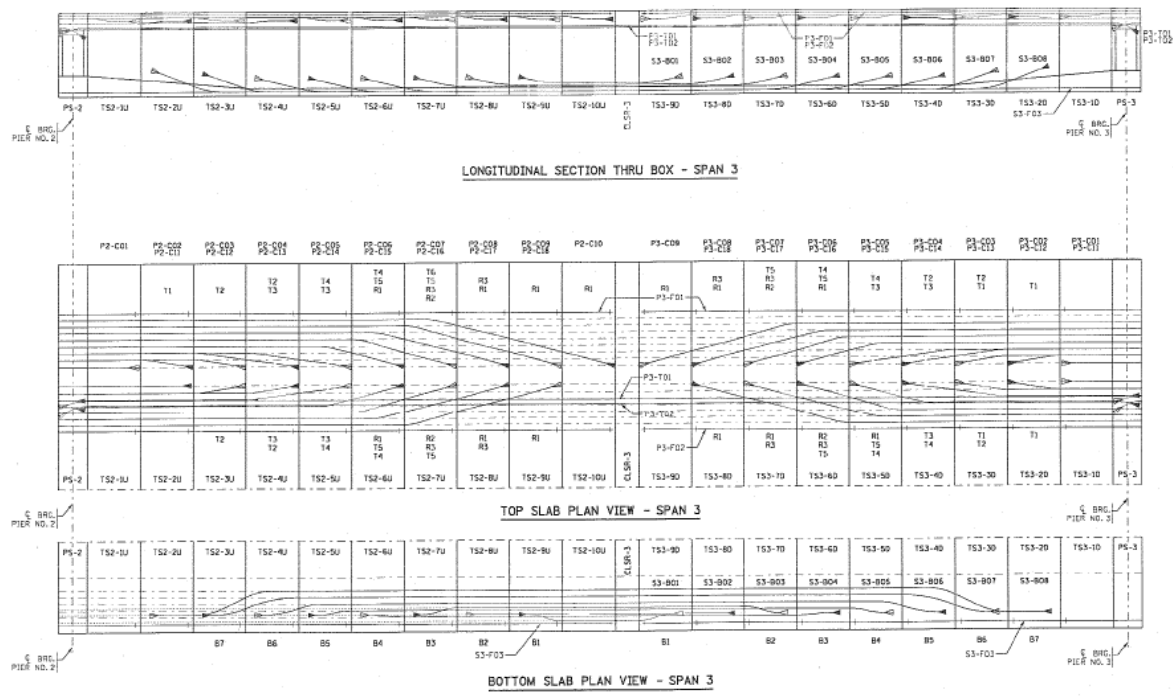


Figure 9: Typical Longitudinal Tendon Layout

ANCHORAGE LOCATIONS

The anchorage location is defined for both cantilever and span tendons. Span tendon anchors in bottom slab blisters are located away from the segment face. Bottom slab blisters must be configured to accommodate any tendon angle that may be required within the span. The blister location must consider jacking clearance, which is a potential issue at terminations near the pier segment, and anchorage congestion. Two scenarios form the bounds for a blister that will be substantial enough to contain the various anchorage conditions. Span tendons terminating near the closure pour require a minimal blister size since the bottom flange is relatively thin. Near the pier segment, however, the bottom slab becomes thicker and a span tendon terminating in this region will have a larger angle change. Congestion is a potential issue not only within the blister but in the bottom slab where continuing span tendons are located. Full detailing plays an important role in the feasibility of blister reinforcement and the mitigation of bar congestion.

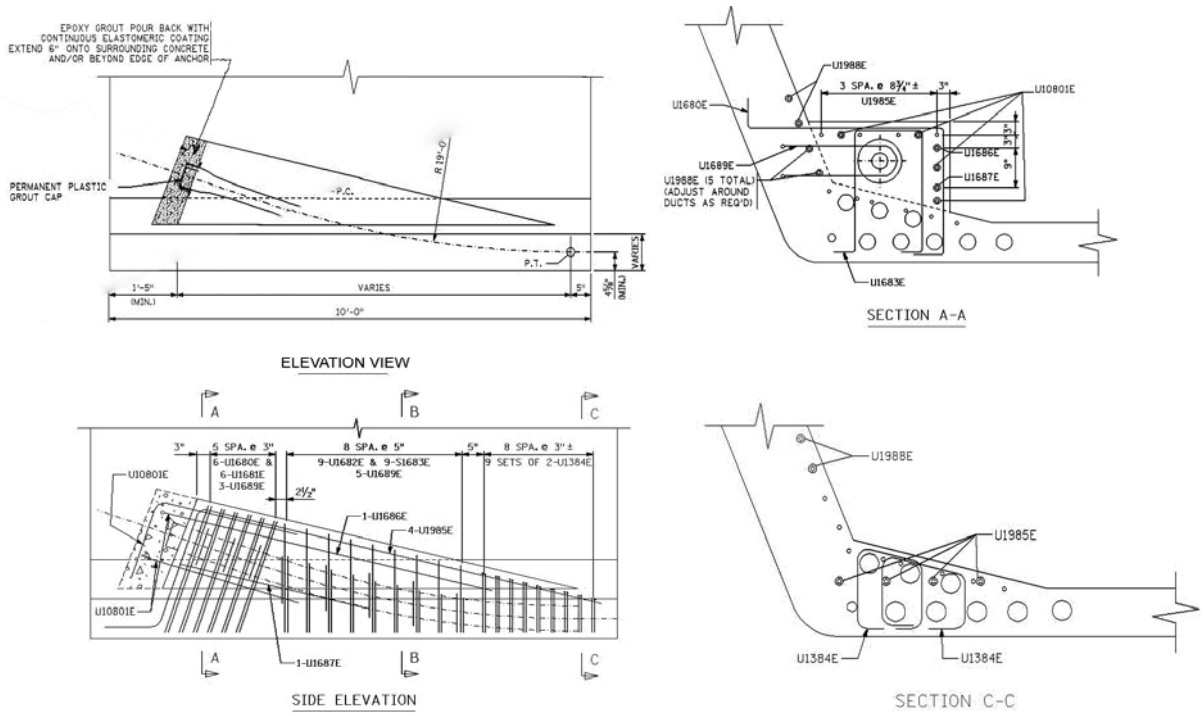


Figure 10: Bottom slab blister details.

Cantilever tendons anchorages are located directly above either side of the web. Designers sometimes have the cantilever tendons anchor in a top slab blister that hangs below the top slab (See Figure 11). However, this arrangement would have required blister formers that fall inside the core form assembly which is expected to be complex given the shallow depth of the cross-section.

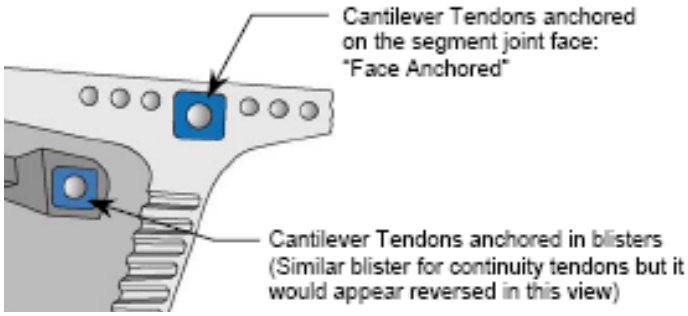


Figure 11: Potential cantilever tendon anchor positions[2].

Another advantage of anchoring the cantilever tendons at the segment face is that the anchor pocket is more easily grouted since grouting is done from the top. Placing anchors at the segment face does have a drawback in that the anchors heads are nearer to the roadway surface. There are various recommendations on the grout pocket details, but the principle is the same: To ensure proper integrity to the anchor protection system. Figure 12 illustrates the

standard treatment of the anchorage pocket. The grouted pocket will be supplemented by the aforementioned two inch overlay and a coating of elastomer in addition to the permanent plastic grout caps.

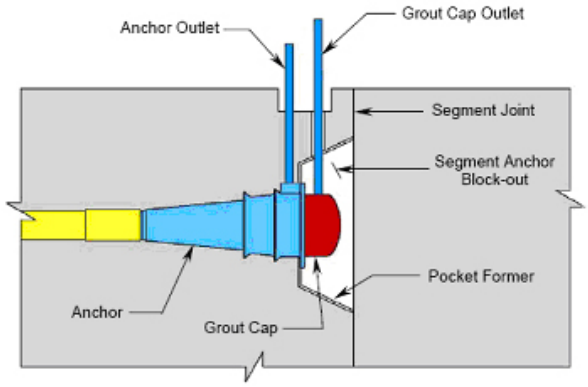


Figure 12: Cantilever Anchorage with Permanent Grout Cap[3].

SEGMENT TYPES

The typical segments shown in Figure 5 are one of three precast segment types on the bridge. The other two segment types are the abutment segment and pier segment. These segments are shown in Figures 13 and 14. They incorporate many of the same features such as web slope and soffit radius, but that's where the similarities to the typical segment end. The abutment segment accommodates a modular joint blockout 24 inches deep by 13 inches wide. Joints were sized to include a 150 degree thermal range and 120% of the movements due to creep and shrinkage. The largest joint required a 9 inch movement rating.

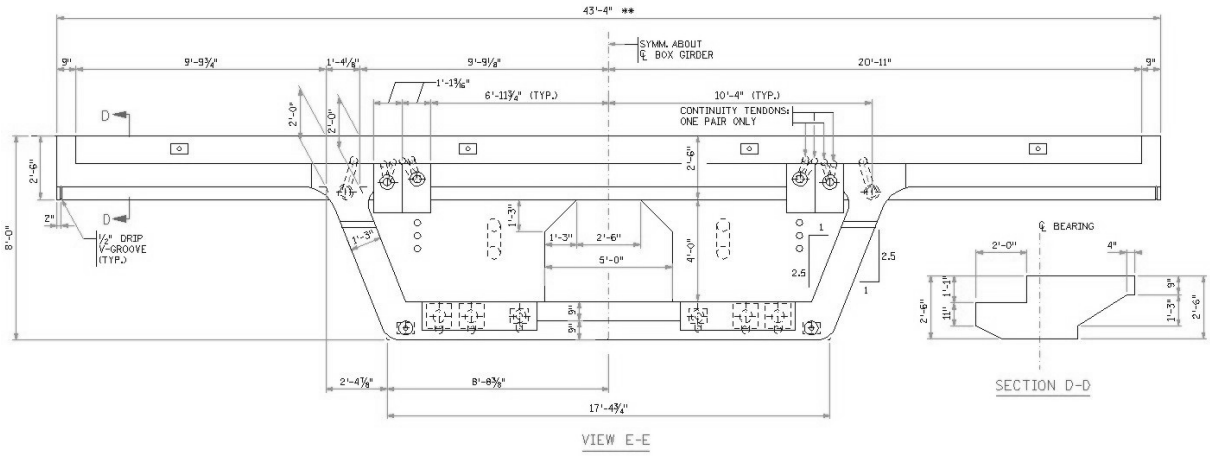


Figure 13: Abutment Segment Looking at Expansion Joint Face.

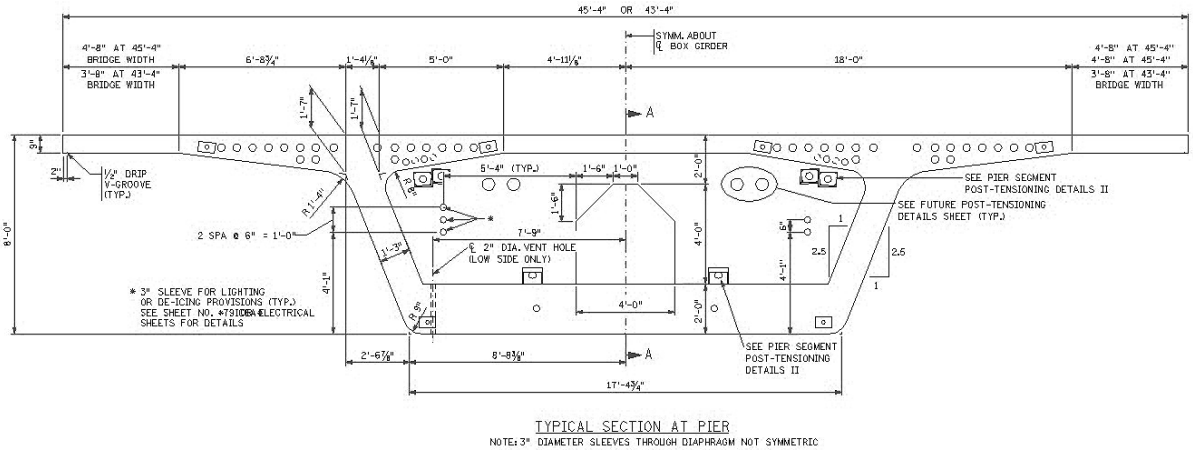


Figure 14: Pier Segment.

Both support segment types include a diaphragm sized to transfer the reactions to two bearings. A two-bearing configuration was selected to control the size of the diaphragm and diaphragm post-tensioning. Diaphragm thicknesses of 3'-0" and 4'-0" were used at the abutment segment and pier segment, respectively, as shown in Figure 15. The pier diaphragm naturally takes more load and required 4 draped tendons each carrying 12-0.6" strand in addition to the aforementioned headed reinforcement. These strands ensure a load path from the webs to the center of the bearing. The abutment segment diaphragm required no diaphragm post-tensioning. The pier segment and pier diaphragm reinforcement are shown in Figure 16.

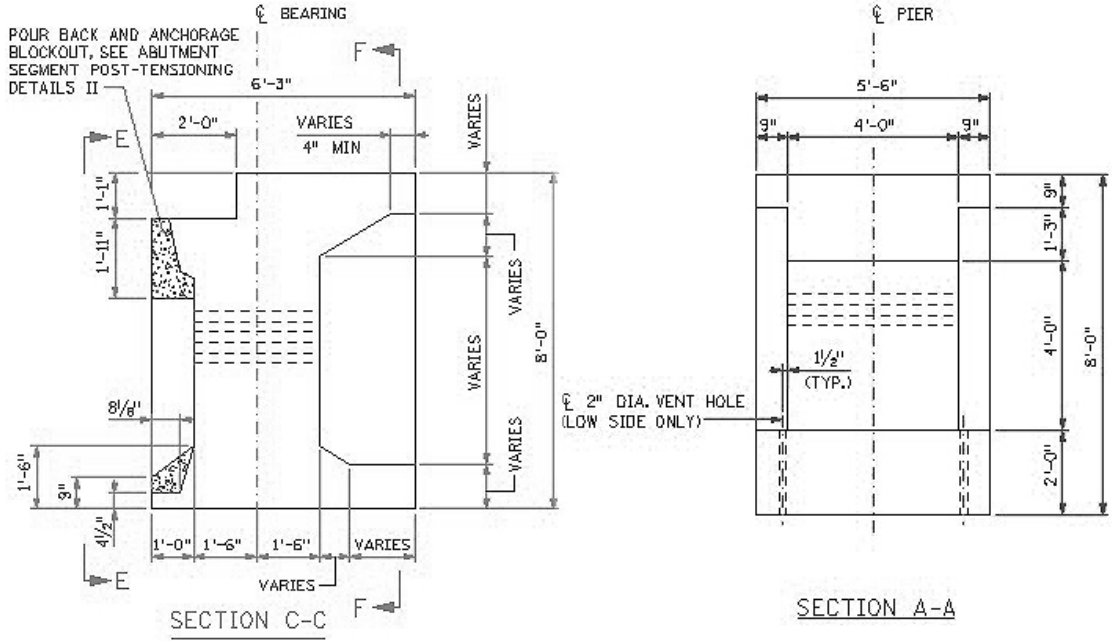


Figure 15: Abutment Diaphragm and Pier Diaphragm

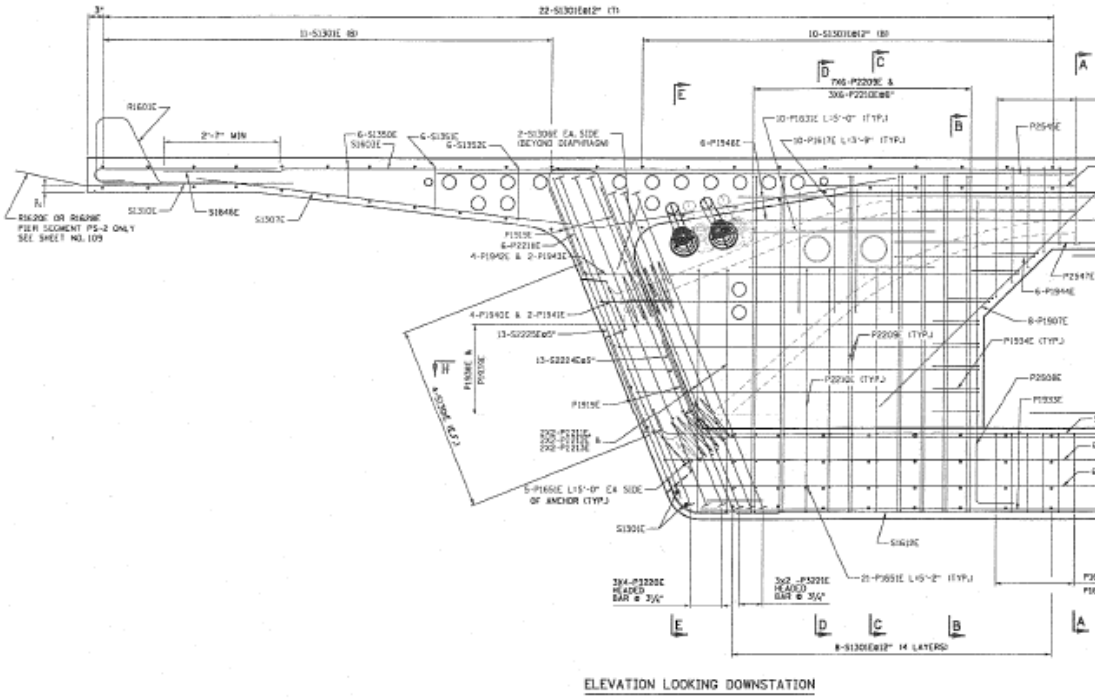


Figure 16: Pier segment reinforcement.

The pier segment required substantial shear reinforcement in addition to draped diaphragm post-tensioning. Headed mild reinforcement was specified to alleviate the rebar congestion problem typical of diaphragm designs. Vertical post-tensioning in the pier segment diaphragm was considered but excluded, even though web post-tensioning is used in the webs of the typical segments. The rationale is that any loss of the vertical post-tensioning in the diaphragm due to roadway contaminants and corresponding corrosion would compromise the strength of the spans, whereas any loss in the webs would at most cause a serviceability concern.

FUTURE POST-TENSIONING

Future post-tensioning provisions provides a means for strengthening the structure in the future should unforeseen serviceability or strength concerns arise. The basic provisions for future post-tensioning include a clear path for tendons capable of imparting no less than 10% of the positive and negative moment post-tensioning forces, and tendon anchorage areas at segment diaphragms. The path provided in the Crosstown Project involves overlapping of tendons at the pier segment diaphragms, which would allow provision of future post-tensioning only in spans needing additional prestressing. The details of this path may be seen in the sections of Figures 17 and 18. At the future drape point, a standard deviator block was developed for use in each span. The tendon location within the deviator block considered the range of bridge curvature and potential conflicts with future post-tensioning, which will be chorded between deviator blocks and support segments. Diablo trumpets were shown at the pier and deviator to accommodate angular variations amongst the six structures. At the

abutment and pier segments it is expected a heavy steel plate will serve as the tendon anchor in the event the future post-tensioning is installed.

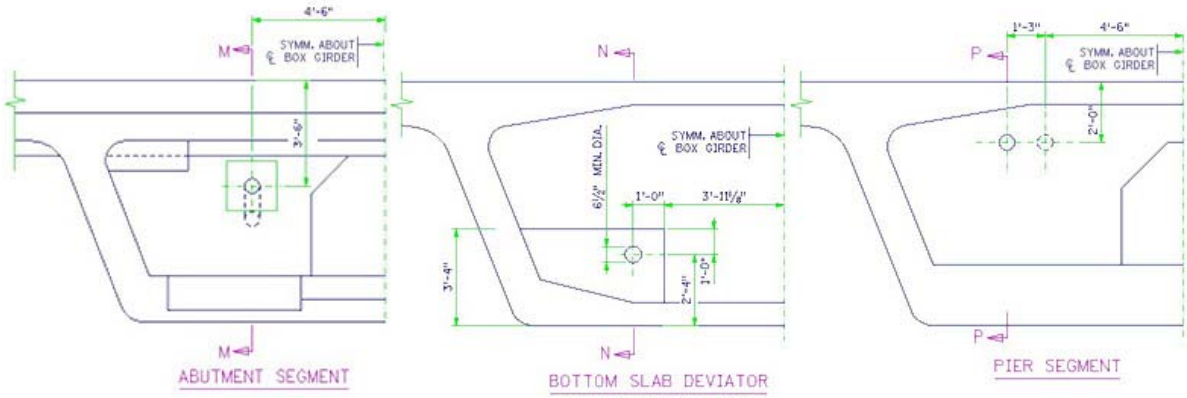


Figure 17: Future tendon path through abutment segment, deviator and pier segment.

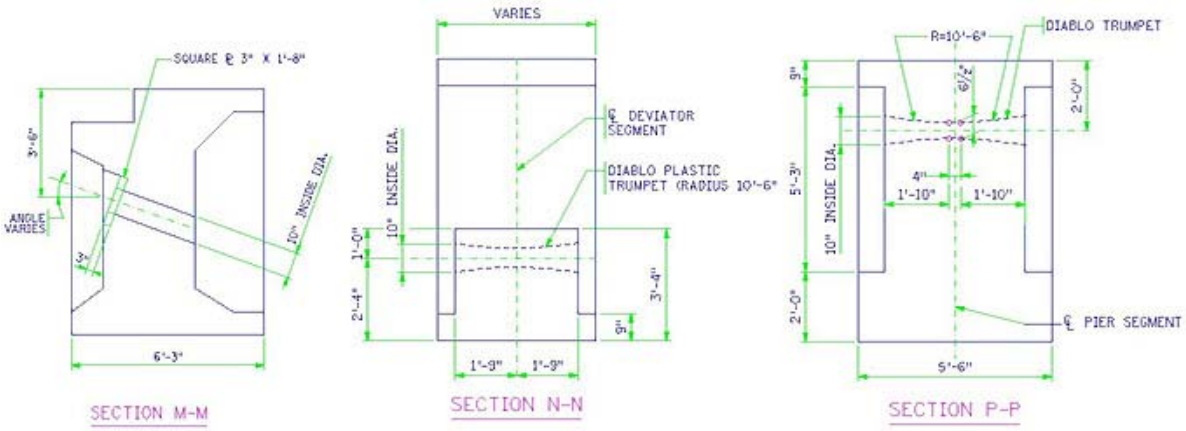


Figure 18: Sectional view of future tendon path.

TRANSVERSE DESIGN

Transverse tendons were designed as the primary reinforcement of the top slab. A transverse profile was generated for each deck width. The tendons are comprised of 4-0.6" dia., 270 ksi, strands in 4" x 1" corrugated plastic flat ducts. Negative moment at the root of the long overhangs for the widest roadway section governed the transverse design in tension at the top of the top slab. For the narrow roadway section, positive moment at mid span between the webs governs the design in tension at the bottom fiber of the top slab. For simplicity in forming and segment fabrication, the tendon size and spacing were held constant for all deck widths.

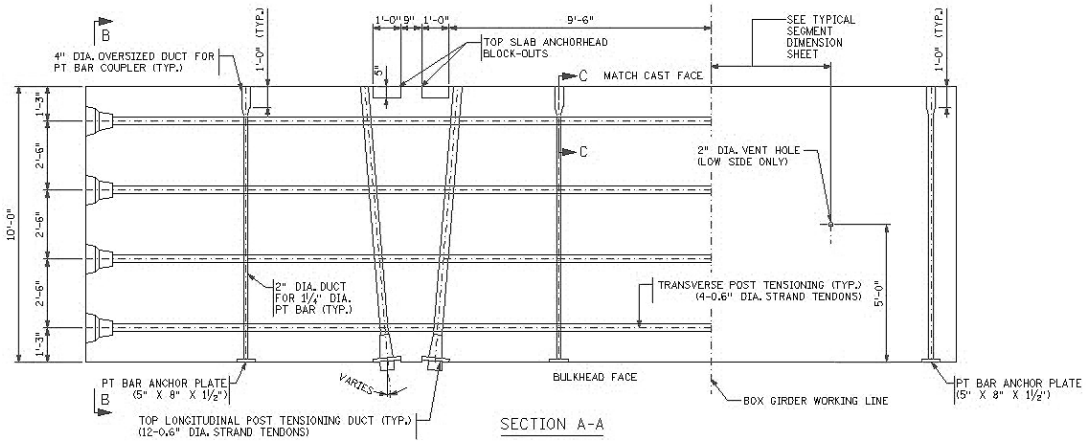


Figure 19: Typical transverse tendon plan.

OWNER'S PERSPECTIVE

Bridge Type Selection

The decision to utilize precast, segmental, post-tension concrete box girder construction was based on a combination of factors.

- The box girder geometry and balanced cantilever construction method offered a construction approach that better fit the confined work area.
- The segments could be erected during brief night-time or weekend traffic closures.
- Steel girder bridges were considered but deemed less desirable because clearance issues necessitated integral pier caps. Integral steel pier caps introduced fracture critical concerns Mn/DOT wished to avoid. Integral post tensioned concrete pier caps introduced vertical clearance problems with their falsework and the staged traffic lanes. Additionally there were long-term maintenance concerns.
- With six bridges and over 450 segments required, MnDOT believed the volume was sufficient to offset the casting yard investment and provide an alternative that was more economical than other bridge types

Considering long term maintenance, costs of future deck replacements, and future painting costs associated with steel girder type bridges, the precast segmental construction offered the most advantages and was the most attractive option.

Consultant Selection

The design of precast segmental bridges is highly specialized and requires expertise and prior experience. Since the MnDOT Bridge Office had not completed prior designs with precast segmental box girders, consultant services were required. Consultant selection was made from a list of pre-qualified firms with previous precast segmental design experience. Three firms were selected, each being awarded two bridge designs. Project magnitude, the time frame available to complete designs, and the desire to distribute consultant work when possible were the primary reasons for three selections.

MnDOT staff understood the importance of an initial standardization effort for precast segmental sections and details to minimize the variability and construction costs. The approach of utilizing a lead consultant to develop segmental bridge standards was employed to provide a template for each designer to utilize. As final design progressed, a "Consensus Building Approach" evolved. Each firm offered their expertise and recent project experiences. The end result was the development of final standards that were utilized for all bridges.

Other Issues

Embarking on precast segmental construction for the first time did present several unique challenges to MnDOT. The design phase of the project was initiated at a time when the LRFD Specification was undergoing a major transformation to include the provisions of segmental construction. This departure from the past use of the "Guide Specifications" for segmental bridges added some difficulty due to the need to work through several AASHTO LRFD agenda items that were approved but not yet incorporated into the current printing of the Specifications. Copies of several AASHTO LRFD Agenda Items were submitted to the designers early on, and were incorporated into project design requirements.

MnDOT made use of experiences from other states, in particular from the evolving technical information on segmental bridges that has been documented by the Florida DOT. Generally, the design directives and special requirements that were being proposed by the State of Florida were regarded as the most current requirements for segmental bridge designs that Minnesota used as a starting point.

One of MnDOT's goals was to provide details that would result in maximum durability. As an example segment joint duct couplers were specified to provide an additional layer of corrosion protection at the precast joints. However, the post-tensioning suppliers had not completely verified that the stringent pressure testing requirements for the post-tensioning systems was achievable with inclusion of the duct couplers. After designs were complete, a contractor questioned how he could provide a bid on a post-tensioning system that included both the duct couplers and the air-tight pressure testing requirements, since the post-tensioning suppliers did not yet have an approved airtight system available for the particular angled tendon geometry layout. In response, MnDOT issued a project addendum late in the bidding process that would still require the use of duct couplers, but changed the air-tight testing requirements. Rather than making the air-tight testing an absolute requirement, a cash incentive payment for passing the pressure testing requirements was written into the Contract. As of the writing of this paper, it appears that the stringent pressure testing requirements will be satisfied based on pressure tests recently completed.

For Bridge Ratings, each consultant was assigned the task of providing a bridge ratings manual for each bridge they designed. Florida publications utilizing the LRFR Bridge Rating Method were useful as a template. It was important to establish the bridge ratings process using the same design behavior assumptions that were made in the original designs which utilized the LRFD method. Using traditional LFD Bridge Ratings procedures would have required extensive re-analysis due to the different behavior models and live load

vehicles in the LFD and "Guide Specifications". Since the LRFR design behavior assumptions are consistent with the LRFD Specifications, the Bridge ratings process was consistent with the design approach.

Because of the complexities of segmental bridge construction verses standard bridge construction, MnDOT has retained a specialty segmental bridge construction engineering firm to augment MnDOT field personnel in administering the construction contract. They will provide rapid review of the Contractor's shop drawings and provide expert advice during construction. The exchange of information and approval process requires quick turn around to Contractor questions and quick resolution to issues as they arise. The three original design firms were each issued a construction contract to address bridge design specific questions that may arise during construction.

As of the writing of this paper, the Contractor has begun to quickly make use of the standardization process that was employed during the design. Some minor adjustments to the bulkhead layout have been proposed, but all designers have indicated that the proposed modifications will have a very small effect on the resulting stresses indicating that the consensus building approach during the design process was a successful endeavor.

CONCLUSIONS

Standards development is a crucial aspect for organizing a multi-consultant design effort. It is rare that bridges having the same construction type be developed under parallel designs by three consultants. However, MnDOT chose to break the design package out for two reasons – to support multiple local consultants and to increase the comfort level of adopting the new construction technique. In this regard the design approach and the development of the design standards served MnDOT well. In particular, MnDOT became part of an ongoing healthy professional exchange on design issues characterized by a mix of professional preference that reflect the equally varied views of the construction industry. The team effort that created six complex bridge designs was a success because it met MnDOT's vision for the future of Crosstown Commons while simultaneously generating confidence in the designs.

REFERENCES

1. Map graphic from MnDOT with permission:
   http://www.dot.state.mn.us/projects/crosstown/maps-projectarea.html
2. FHWA Post-Tensioning and Grouting Manual, May 2004, Chapter 2, p.22
3. FHWA Post-Tensioning and Grouting Manual, May 2004, App. D, p.15

Reinforcement in the footing on 6-ft-diameter drilled shafts. Photo: Ohio Department of Transportation.

In consideration of the desire to maintain operations in the zoo at all times, it was proposed to use precast arch rib segments.

Thrust blocks located within the Cleveland Metroparks zoo. Photo: Ohio Department of Transportation.

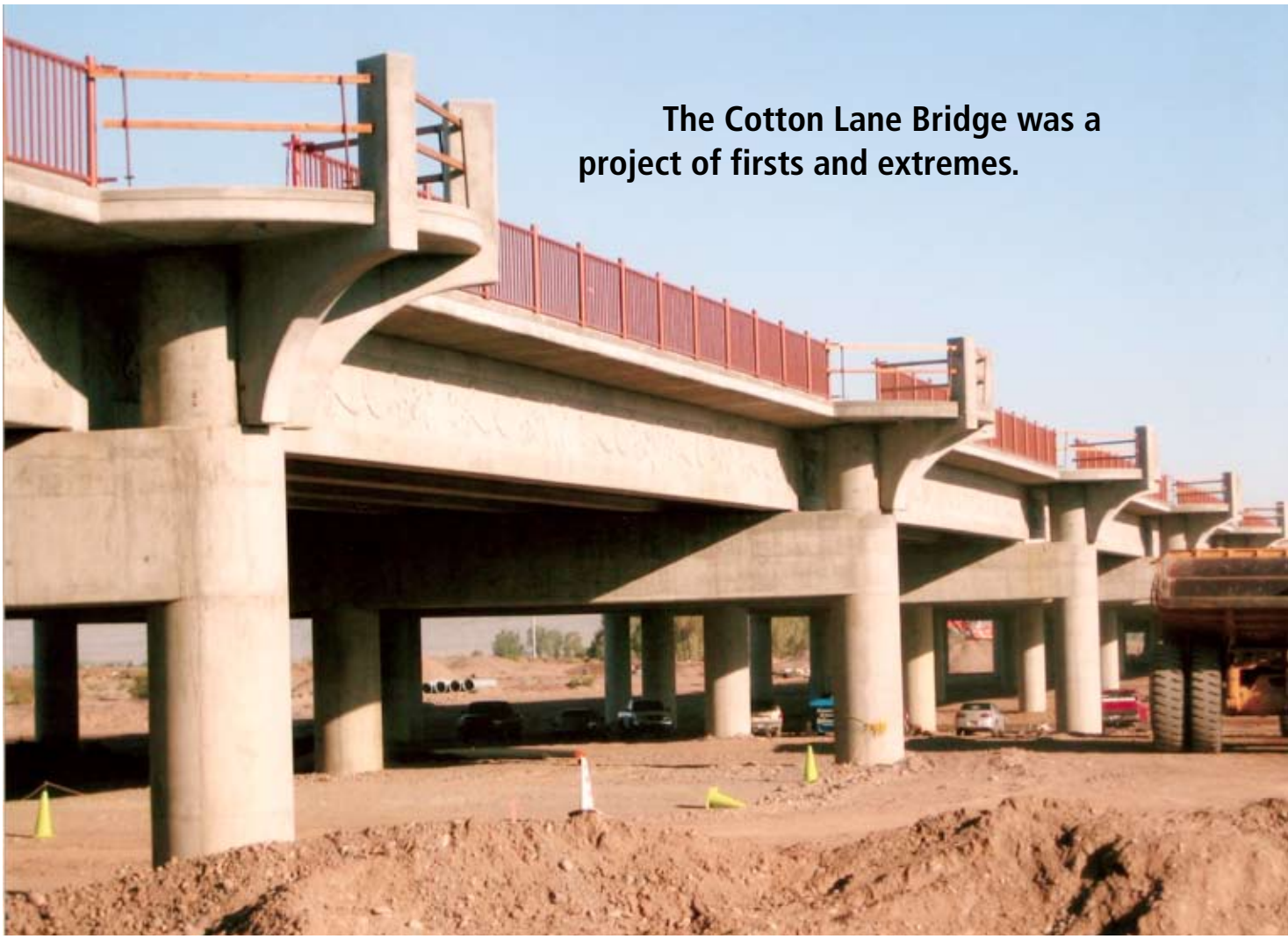
COTTON LANE BRIDGE / GOODYEAR, ARIZONA

COTTON LANE BRIDGE / GOODYEAR, ARIZONA

Precast girders aided sustainability factors by reducing construction waste, minimizing transportation costs, and contained Type F fly ash..

The CMAR process allowed local precasters to be involved in the design process.

COTTON LANE BRIDGE / GOODYEAR, ARIZONA



The Cotton Lane Bridge was a project of firsts and extremes.

COTTON LANE GILA RIVER BRIDGE – INTEGRATION OF ENVIRONMENT AND INFRASTRUCTURE

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ABSTRACT

It is often difficult to blend the design of highway bridges with the surrounding environment. The recently constructed Cotton Lane Bridge over the Gila River at Goodyear, Arizona features a unique design that not only uses the site's natural surroundings for inspiration, but incorporates them without large scale land transformation. Primary goals for the design aesthetic included visual access to the mountain horizon and the riverine environment, as well as support for native geomorphic and biotic processes with materials, colors, and patterns. On vertical concrete surfaces, unpainted sandblast and simulated sandblast textures reveal both prehistoric and familiar desert life. The outboard face of the exterior precast, prestressed girders uses form-liners to create gecko and cactus imprints. The bridge's pier columns also feature artistic impressions of Goodyear's ecosystem, with ancient life forms such as water scorpions and dragonflies exposed by sandblasting. Patterns in the safety barrier reveal saguaro cactus, the bats that pollinate them, and a moon form. All pier columns were stained copper oxide color up to the 100 year flood elevation to suggest the wet-dry desert riparian cycle and to connect with the copper mining history of the region.

Keywords:
Aesthetics, Environment, Bridge

INTRODUCTION

Increased traffic volumes and congestion, dynamic suburban residential development, and a river habitat enhancement initiative worked together to create the need for a unique bridge across the Gila River in Maricopa county. The City of Goodyear has experienced rapid residential development in recent years. Major parts of the community were separated by the Gila River. City officials wanted to connect these areas and consolidate development on the north side of the river with a major north-south arterial that would cross the river at the foot of the Estrella Mountain formation. Maricopa County transportation officials, along with several private developers, wanted a bridge that could be constructed quickly and cost-effectively Both the developers and the sponsors of a river habitat enhancement effort wanted to make sure that bridge styling and appearance fit with outspoken local preferences for a rustic and natural appearance. Further, the City of Goodyear was concerned about how the bridge would impact their "dark sky" requirements. A unique partnership of county, city, and private developers was forged to address the varying interests and needs of each stakeholder. Using a construction management at risk (CMAR) contracting method, engineers, landscape architects, contractors, and project partners addressed these needs through unique design and construction solutions for the Cotton Lane Bridge over the Gila River.

OVERVIEW

In combination with a proposed river habitat enhancement program, hydraulic analysis indicated that a 2,100 foot long bridge was necessary to span the Gila River and properly connect with planned freeway alignments. A traffic analysis recommended an ultimate capacity of three travel lanes in each direction on the bridge. The City of Goodyear and the developers required a six-foot wide sidewalk on each side of the bridge to encourage pedestrian traffic across the river. A bridge type study revealed that traffic and hydraulic needs could be satisfied with a structure consisting of 17 spans of about 122 feet each, utilizing AASHTO Type VI modified prestressed girders. County and river improvement officials insisted that the designers use a context sensitive approach. The designers recommended that conceptual design be driven by an intensive collabaration between project sponsors, engineers, landscape architects, and contractors.

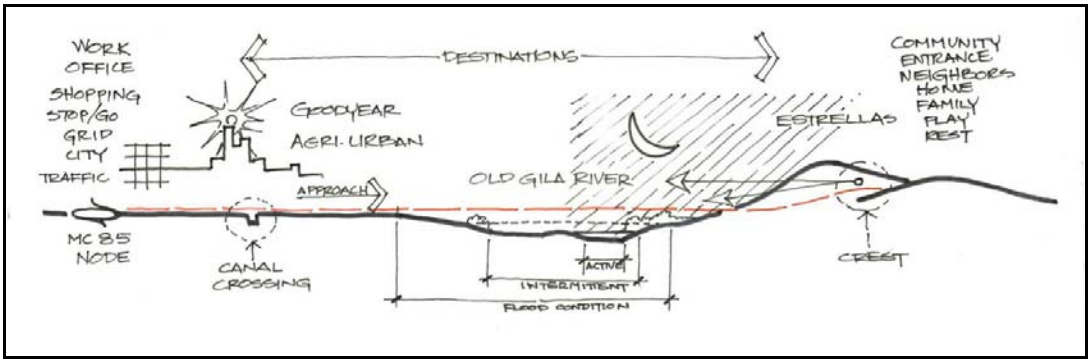

Figure 1: Context Section

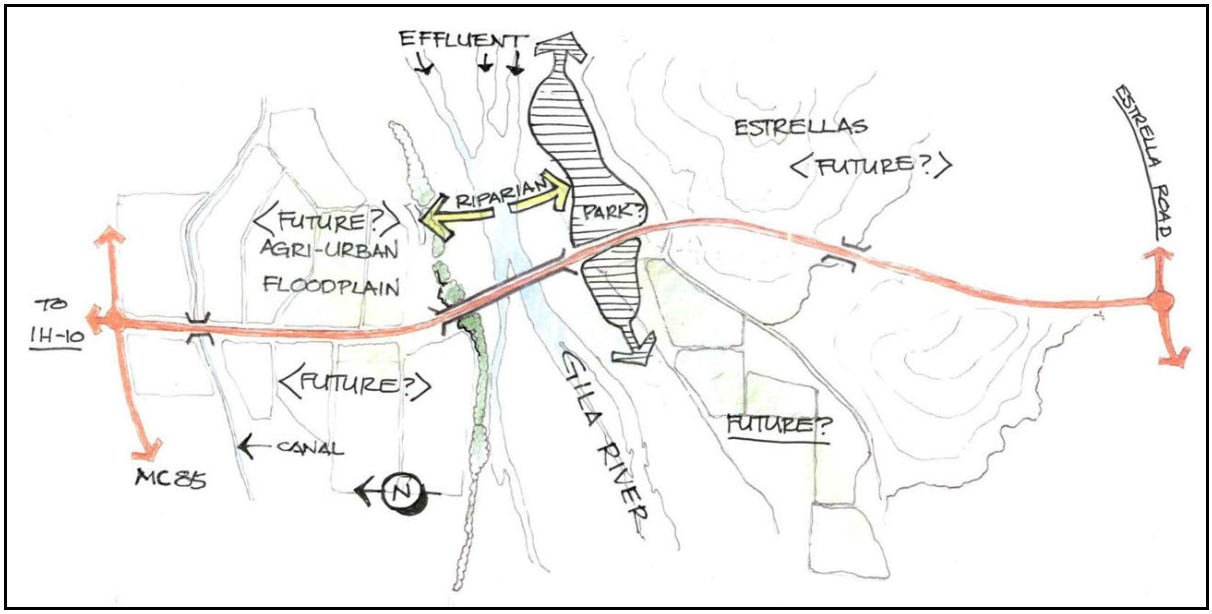

Figure 2: Context Elevation

Designers began the charrette process by conducting a graphical site analysis, which observed the various visual, geographical, cultural, and social contexts associated with the use and siting of the bridge, as can be seen in Figures 1 and 2. Fueling the conceptual design process was the idea that motorists' experience of the mountains, river, and flood plain environment in Goodyear would be shaped, in part, by the physical attributes of the bridge. The design charettes used the highly interactive process shown in Figure 3, which included high levels of participant involvement. The participants explored the various aesthetic options and conceptual themes associated with different bridge types in order to effectively blend appearance with functionality in the design. A "Rapid-viz" visualization process was used, whereby the charette facilitator conducted on-the-spot sketching in order to receive immediate feedback and alternatives from the participants.

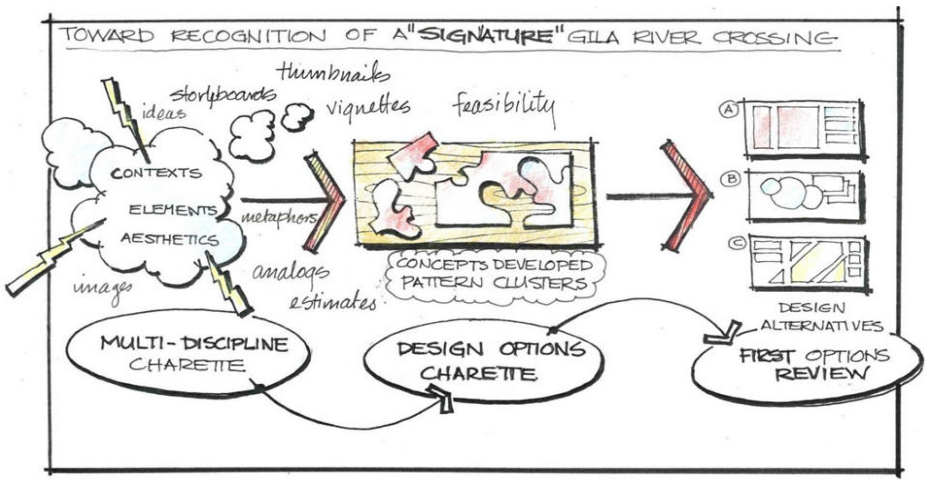

Figure 3: Concept Development Process

The Rapid-viz technique (Ref. 1) is similar to drawing short hand, using symbolic images to represent verbal ideas. It not only eliminated the designers' need for an elaborate sequence of presentation boards, but also allowed them to expedite the process of generating, assessing and refining concepts for basic structural forms and styling. It can be geared to encourage real time participations in a workshop context. Or it can be used to reduce studies and time devoted to polishing formal alternatives panels. Comments from specialists in different disciplines can be incorporated into design development instantaneously. Figures 1, 2, and 3 illustrate some of the ways that Rapid-viz was used in this project.

Since the scope and goals of the project were broad and somewhat unrestricted, the project used a CMAR contracting method, which allowed the contractor to contribute to the design process. Participation from the contractor helped to ensure that the costs, schedule and constructability were reasonable and acceptable to the project stakeholders and that design goals were feasible to construct. The CMAR process also provided greater access to the local precasters in order to determine most effective solutions.

The project was funded through a unique public/private agreement. Maricopa County Department of Transportation, the City of Goodyear, and two private developers representing the neighboring housing developments participated in financing the bridge's construction cost. Because each contributor was allowed a role in the development of design aesthetics, conflicting concerns about cost, schedule, and aesthetics arose. The design charettes allowed involvement and contribution from all participating parties, resolving many differences early in the design process.

Figure 4: Drilled Shaft Load Test per Osterberg Cell Method

In an effort to achieve cost savings without compromising any of the stakeholders' interests, the team utilized creative cost saving strategies. Precast concrete was used where possible to

minimize construction time, cost, and adverse impact to the environment. Additionally, a static dilled shaft load test utilizing the Osterberg Load Cell was performed during early design as shown in Figure 4. Due to the higher reliability of the soil response obtained thru use of this load test, a reduced safety factor, as permitted by the AASHTO LRFD code (Ref. 2), was correspondingly permitted in design. Savings in the foundation far outweighed the cost of the load test and resulted in net savings of more than $1M to the project.

Through a Clean Water Act Section 404 Individual Permit (IP), which is regulated by the U.S. Corps of Army Engineers, the bridge construction project now contains 859 acres of habitat enhancement mitigation measures to off-set construction impacts to the Gila River. This IP authorized the largest amount of construction related impacts in Arizona to date. The bridge project is also linked to the Flood Control District's Rio Salado Project, a habitat enhancement and flood control project. This project will enhance over 18 miles of riparian habitat along the Gila River Corridor while providing flood protection to the Town of Buckeye. The project will also decongest the river by removing not-native plants and restoring the Gila River to its natural state.

CONTEXT SENSITIVE DESIGN

The County Transportation Engineer admonished the Design Team that what is done at this bridge crossing project would forever change the environment. He insisted that concept development be sensitive to the physical environment and biotic communities.

The design team introduced concepts of environmental and local landscape preservation early in design discussions. Dialog often centered around two questions: "How would nature build this?" and "How would nature help to achieve a desirable aesthetic result?" The charette process produced several ideas that shaped structural and aesthetic treatments. One element of the design aesthetic was inspired by the nature's own process of erosion. Stencil and sand blast techniques were used to reveal fossil-like patterns of prehistoric creatures and plants on columns. The same process was used for reveling contemporary life forms on the back of the traffic barrier, as shown in Figure 6. To achieve this weathered and eroded appearance on specially designed precast girders, designers used custom made form liners in girder production molds to reveal gecko patterns like the one shown in Figure 5. Since local aggregate was used for the cast-in-place concrete, the only paint used on the project simulated a stain that might be left on bridge piers after a major flood event originating in the upstream copper mining district.

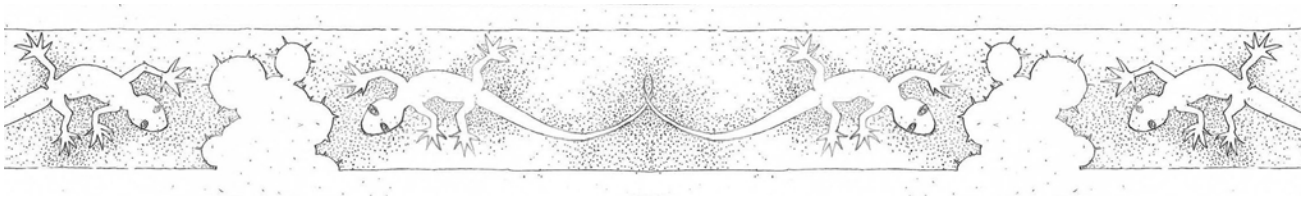

Figure 5: Preliminary Sketch of Life Forms to be Integrated within Girders

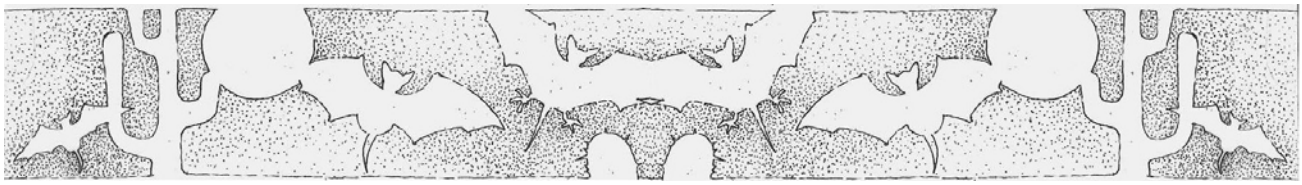

Figure 6: Preliminary Sketch of Life Forms to be Integrated within Traffic Barrier

Arizona's history is deeply connected with that of the copper mining industry in the United States. The region surrounding the Gila River, in particular, remains rich with copper today. As a means of incorporating copper into the design, a pale green shade, resembling oxidized copper, was used as an accent in many of the bridge's stains, including the railing (Figure 7) as well as the pavers off the bridge that comprise the median flatwork.

Desert storms produce sudden, often turbulent floods that can act as abrasive forces on bridges. Bridge piers were extended above the Gila's riverbed, and coated with a water-borne stain. The stain was the same pale green, oxidized copper shade as the other stained areas of the bridge.

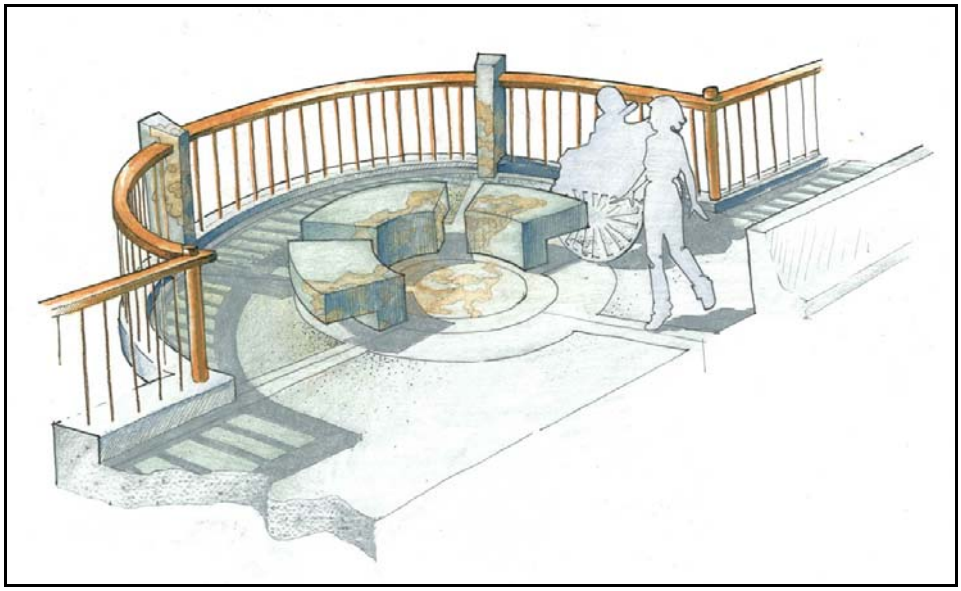

Figure 7: Preliminary Sketch of Alcove with Copper Accents in Railing

In an effort to preserve motorists' view of the Estrella Mountains, the bridge was designed to have only a slight vertical curve, with no pier structures or light poles breaking the horizon. The addition of the minimized arch required less fill than that of a flat profile, and therefore, less harmful impact to the Gila River. Shortened light poles with low-intensity lighting were used to comply with the City's light pollution and "dark sky" ordinances, providing the effect shown in Figure 8.

Figure 8: Preliminary Sketch of Bridge at Night – "Dark Sky" Requirement

The bridge's design was also driven by an awareness of the Gila's River environment. Driving at 60 mph, drivers would have almost 30 seconds of viewing time on the bridge. Designers wanted barriers that would allow motorists and pedestrians to look at the riverbed. Design of the bridge included a series of alcoves and benches, as shown in Figure 9, inviting pedestrians to gaze at the river and enjoy the natural surroundings. The versatility of precast concrete made the addition of the alcoves feasible, with the alcoves' concrete corbels serving as the false work system for the alcove slabs during construction. Pedestrian walkways were further enhanced with a design of native bats and cacti on the back face of the traffic safety barriers.

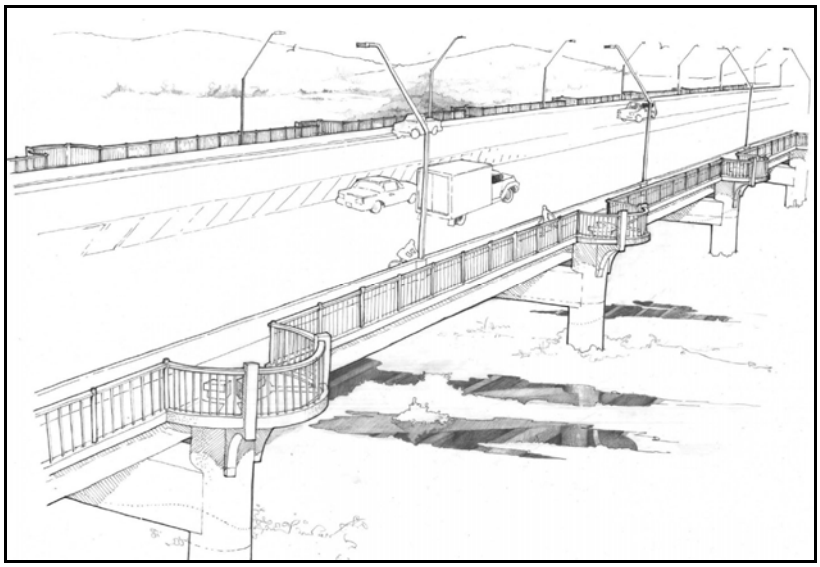

Figure 9: Preliminary Sketch of Bridge with Pedestrian Alcoves

APPLICATIONS

A relief pattern was applied to the outboard faces of the exterior precast prestressed girders in order to reveal the gecko patterns shown in Figures 10 and 11. This resulted in unsymmetrical girder section, which required special design and detailing. During design of these girders, the design team worked with the contractor and local girder precasters to determine the most cost effective way to incorporate the form-liner into the girder prior to prestressing.

Figure 10: Exterior Girder with Embedded Gecko & Cacti Pattern

Figure 11: Construction prior to Deck Pour

Pier lines on both sides of the bridge feature half circle pedestrian alcoves supported by two precast curved corbels as shown in Figure 12. These alcoves are 9'-9" in radius and feature precast park benches. Eventually, the alcoves will also feature the work of local artists or informational plaques on the local history and environment. Inviting pedestrians to rest and view the natural surroundings, the alcoves allow the bridge to act as more than simply a conveyance over the Gila River.

Figure 12: Pedestrian Alcove with Precast Corbels

The alcove slab and adjacent sidewalk area feature exposed aggregate with stain. The exposed aggregate finish was achieved by sandblasting around the patterns after concrete placement. Further enhancing each alcove is a bat and cacti pattern, like the one in Figure 13, that is displayed on the back face of the F-barrier.

Figure 13: Relief Pattern on Back Face of Barrier

The pier columns received a treatment of stain and sand-blasted patterns, as Figure 14 shows. The stain on each column extends up to the 100-year storm elevation in order to suggest the abrasive and eroding capability of the floods over time.

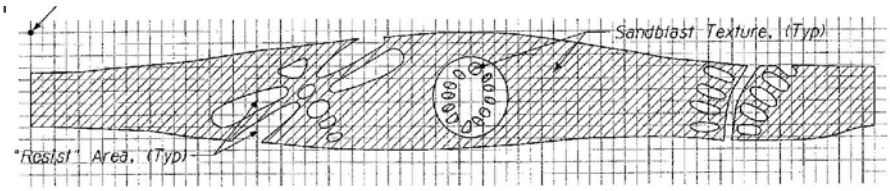

Figure 14: Stain and Pattern on Columns (Constructed Photo not available yet)

CONCLUSIONS

From charettes to construction, design of the Cotton Lane Bridge over the Gila River in Goodyear, Arizona, balanced the stakeholders' need for an attractive, functional, and pedestrian-friendly bridge with their concerns about environmental context and sensitivity. The collaborative nature of the conceptual design expedited the design process. Such concern for preservation of the local landscape influenced designers to use specific colors, materials, and textures, while the awareness of the Gila's River environment and inhabitants shaped the bridge's form. Above all, the versatility of precast concrete, from the modified exterior girders to the curved corbels at the alcoves, enabled and provided for a more cost efficient, environmentally friendly, quickly constructed and unique bridge.

REFERENCES

1. Hanks, Kurt, "Rapid Viz, Third Edition, A New Method for the Rapid Visualization of Ideas", William Kaufmann Inc., 2006.
2. AASHTO 2004 LRFD Bridge Design Specifications, Customary U.S. Units, 3rd Edition, American Association of State Highway and Transportation Officials, Washington, D.C.

ADVANCED AESTHETIC EMBEDMENT IN PRESTRESSED GIRDER

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ABSTRACT

For the recently completed Cotton Lane Bridge over the Gila River in Goodyear, Arizona, architectural form liners were embedded into the outboard face of the exterior modified AASHTO Type VI girders. The girders were modified by increasing the web thickness and by curtailing the top flange on one side to create a C-shaped section. The resulting deep outboard girder face received a relief pattern of lizards and cacti. The asymmetric girder cross section required a modified prestressing strand pattern. Due to the non-symmetry additional torsional shear stresses and weak axis bending were introduced. Increased torsional rigidity of the modified girder compared to the non-modified interior girders influences the live load and composite dead load distribution. Eccentricity between centroid of prestressing strands and centroid of section caused horizontal bowing. The unsymmetrical girder needed to be adequately braced during concrete deck placement to minimize both additional torsional stresses and non-uniform pressure on the bearing pads. The paper discusses these and other design issues as well as the construction of the Cotton Lane Bridge in detail.

Keywords
Aesthetics, Concrete, Unsymmetrical, Prestressing, Precast

INTRODUCTION

Design of the new Cotton Lane Bridge was driven by Goodyear, Arizona's rapid growth and suburbanization, and the resulting need to span the Gila River with an attractive, cost-efficient structure. In order to create a visually interesting structure, architectural relief patterns were cast directly into the prestressed concrete bridge girders. Each panel was embedded with a Southwestern-themed lizard and cacti pattern, eliminating the need to hang patterned panels after girder placement, and thereby decreasing construction time. This approach enhanced aesthetics without sacrificing economy. However, incorporating this pattern into prestressed girder sections increased the complexity of both the design and construction, as will be shown in this paper.

Recently constructed, the Cotton Lane Bridge over the Gila River is a 17 span, 2,067-foot long bridge with a bridge deck that is 114-feet wide. Each span measures approximately 122-feet from pier to pier, and consists of 12 girder lines spaced at 9'-5" centers. The cast-in-place deck is eight inches thick. Each pier was made from cast-in-place concrete and consists of a 5-foot wide pier cap, supported on four columns, each 5-foot in diameter which transition directly into drilled caissons that are 6-foot diameter. The outside face of all 34 exterior girders received a relief pattern of lizards and cacti, totaling approximately 4,080 linear feet. The ten interior girder lines consist of typical AASHTO Type VI modified prestressed girders. Figure 1 shows the modified exterior girder at the precast yard. Figures 2 and 3 are in-construction pictures taken at the job site.

The bridge owner is Maricopa County Department of Transportation and the general contractor is Peter Kiewit & Sons. The girder precaster is T-PAC.

Fig. 1 Exterior Girder at Precast Yard (After Stripping)

Fig. 2 Girder Placement at Job Site (Before Deck Pour)

Fig. 3 Exterior Girder at Job Site (After Deck Pour)

DESIGN CONSIDERATIONS

This section examines the unique design considerations that are associated with using embedded form liners within prestressed bridge girders. The architectural pattern is 3'-6"

deep with ¾ in. maximum relief depth. The inboard face of the girder has the same profile and dimensions as the AASHTO Type VI section. Web thickness was increased to 14-inch, which resulted in a 24-inch wide bottom flange and a 31-inch wide top flange. These modifications resulted in the C-shaped asymmetric section shown in Figure 4.

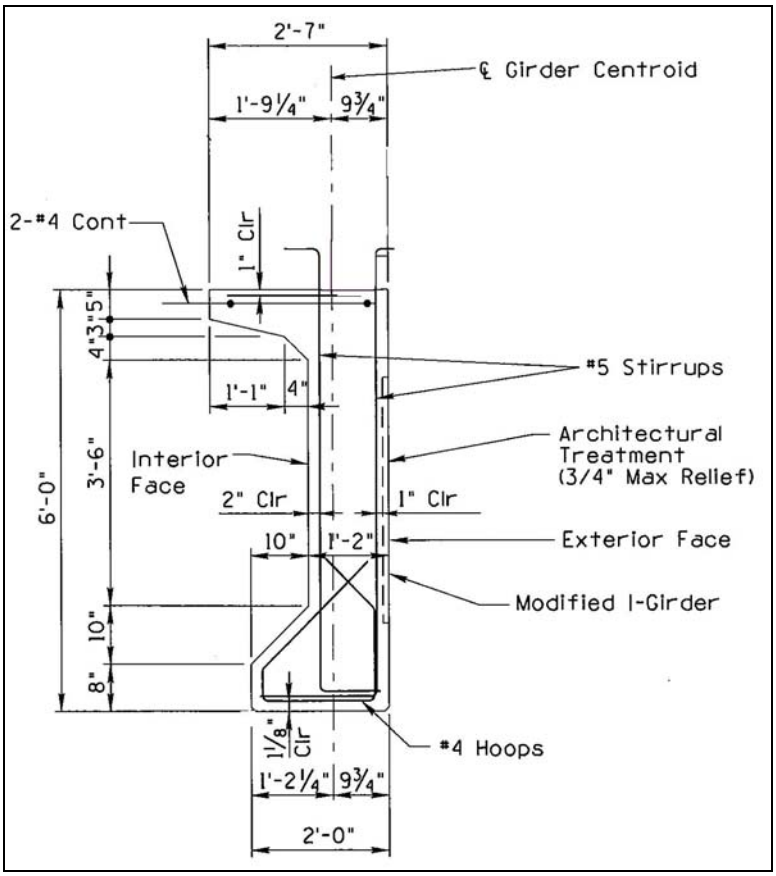

Fig. 4 Typical Cross Section

Due to the asymmetry, the principal axes do not coincide with the vertical and horizontal directions. The deviation is very small (less than 1.3 degrees) so that principal section properties do not differ much from the properties about the original axes. However, it is important that the applied moments are properly decomposed into principal axes components. Moments about the horizontal axes due to prestressing and dead load are large and thus cause appreciable moments about the weak principal axis which cannot be ignored for stress and deflection calculations. An additional complication is that the shear center is about 6-inch horizontally eccentric with respect to the centroid, which creates additional torsional stresses.

Figure 5 is the strand pattern that was used for these modified exterior girders. The girder is prestressed using 53 - 0.6-inch diameter 270-ksi low relaxation strands stressed to 202.5-ksi. Forty-one of these strands are straight, while the remaining twelve strands are harped with hold-down points located at a distance of 12-feet on either side of the midpoint of the girder.

Because of the draped pattern, debonding of strands to control stresses near the girder ends was not necessary. The specified 28-day concrete strength was 6,500-psi.

This asymmetric section required a modified prestressing strand pattern. The modified strand pattern shown in Figure 5 was chosen, in part, to minimize the horizontal eccentricity between centroid of section and center of gravity of prestressing. The final eccentricity was only ¼ inch. However, even with such a small eccentricity the effects on girder stresses and deflections need to be accounted for in design due to the small stiffness of the girder about its weak axis.

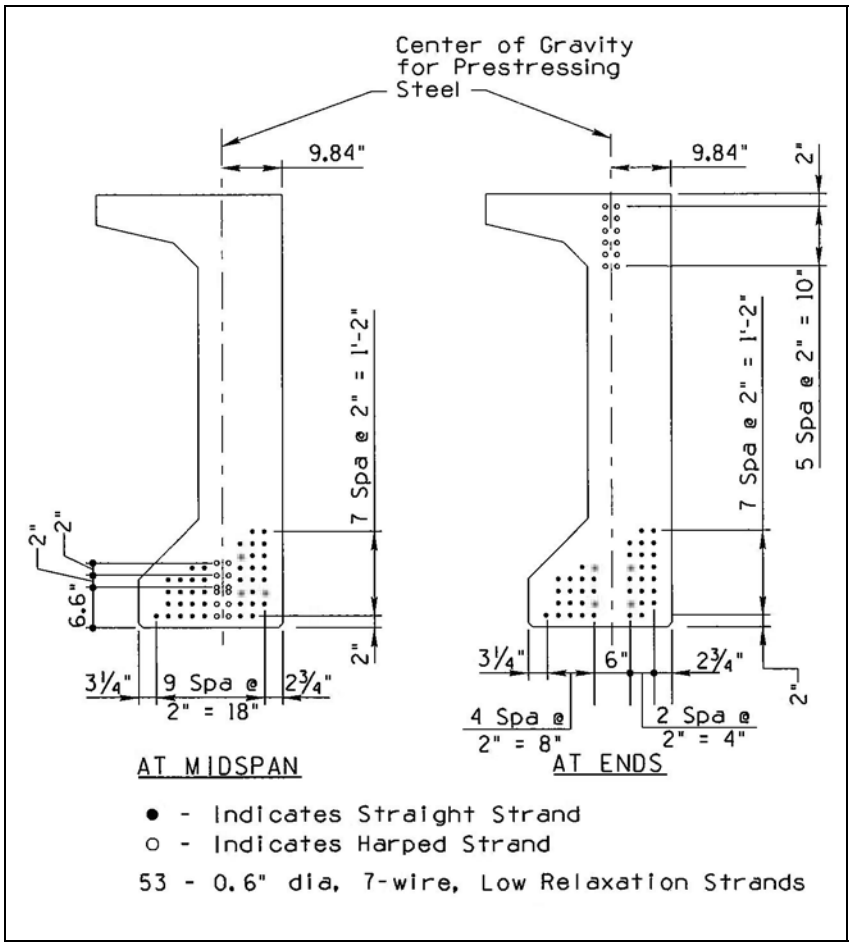

Fig. 5 Prestressing Strand Pattern

At various locations along the girder, additional tensile and compressive stresses reaching up to 300 psi resulted from the weak axis bending under prestressing and non-composite dead loads. These additional stresses, either tensile or compressive, were appropriately combined with the traditional stresses to ensure the code limits were not exceeded. For loads on the composite system the stiffness of deck and diaphragms prevents horizontal girder displacements, which justifies the common assumption that vertical and horizontal axes are principal directions of the composite edge girder.

Due to weak axis bending and principal axes rotation, horizontal bowing at transfer is much larger than for conventional, symmetric girders. For the Cotton Lane Bridge the calculated horizontal displacement at midspan under self weight and prestress was 1.70 in. on 119'-8" girder length. Because horizontal bowing can impact deck forming operations as well as intermediate diaphragm forming operations, the contractors needs to be informed of and plan for the anticipated horizontal bowing. This is best done by indicating the anticipated bowing at release on the contract drawings. The precaster is typically limited to a sweep tolerance of 1/8 inch per 10-feet of girder length (Ref. 1). If horizontal bowing is anticipated, then the tolerance limit should only be applied to the deformation difference from the anticipated value. Similarly to camber growth, horizontal bowing will grow with time due to creep until diaphragms in the completed structure restrain further growth.

Increasing the torsional rigidity of the modified exterior girder influenced both the live load and composite dead load distribution to the girder. The modified load distribution needs to be investigated and determined before the girder can be properly designed. Performing a grid analysis provides a more realistic estimate of how the live loads and composite dead loads will distribute to the girder lines.

Fig. 6 Girder Elevation with diaphragms

Per Reference 2 torsional rigidity does not significantly influence life load distribution as long as the moment of inertia is at least ten times greater than the torsional stiffness. For the Cotton Lane Bridge this requirement was just satisfied. However, in order to better understand the likely distribution of loads between the girder lines a grid line analysis was performed and compared to the AASHTO LRFD distribution factors. The grid analysis results were found to be within 10% of the AASHTO values and the AASHTO values were used for design.

Self weight and initial prestressing force introduced torsional shear stresses up to a maximum of about 90-psi, due to the approximately 6-in. eccentricity of the shear center with respect to the centroid of the section. Concrete diaphragms were installed prior to placement of the deck concrete in order to minimize the introduction of additional torsional stresses due to superimposed dead loads. The intermediate diaphragms were located at the third points between all girder lines and the end-bracing diaphragms were located five feet from the girder ends between exterior and first interior girders only (Figure 6). The location of the end-bracing diaphragms was selected to not interfere with the pier diaphragms, which were placed concurrently with the concrete for the deck.

These end-bracing diaphragms provided an added benefit in that they prevented rotation at the girder ends. By preventing this rotation, the non-uniform pressure on the elastomeric bearing pads was limited to that caused by the weight of the girders themselves.

CONSTRUCTION CONSIDERATIONS

This section presents several of the unusual construction considerations that arose from the use of the C-shaped edge girders with embedded form liners and the on-going dialogue between the designer and the precaster from early design to construction.

Fig. 7 Unloading Girder at Job Site

In early design, the local precasters were contacted in order to discuss various aesthetic modifications to standard girder sections and to understand their constraints and limitations. For special projects such as this, a good relationship must be established between the designer and the precaster. Before deciding on the use of the C-shaped edge girders with embedded form liners, several other aesthetic enhancements were considered. Precast

patterned panels hung on traditional exterior girders were considered and dismissed because of the lesser aesthetic qualities (vertical joints between the panels) and long-term maintenance needs. Trapezoidal tub girders in lieu of AASHTO girders were considered and dismissed because of the high cost of purchasing the necessary steel forms.

One consideration associated with the C-shaped sections is that the modified girder was heavier due to the increased web thickness. Therefore, local precasters were contacted to determine the maximum efficient girder shipping weight. If a girder is too heavy, special transportation vehicles and hauling permits may be required, which will impact cost and time. Additionally, lifting devices need to be checked for adequacy. During the Cotton Lane Bridge project, the local precaster was able to accommodate and ship the 80 ton girders to the job site. Figure 7 shows the exterior girder being unloaded at the job site. Figure 8 shows the custom form created for the outboard face.

Once stripping is complete, the precaster must evaluate which way the girders will face while being stored in the yard prior to shipping. Girders should be oriented in such a way that bowing caused by environmental temperature changes are minimized. Further, the direction the girder is bowing due to the eccentricity between the prestressing and the section centroid should also be considered. The Cotton Lane Bridge spans primarily North-South which means the exterior girders on one side face East and face West on the other side. Once the girders were placed at the job site and prior to placing diaphragms and deck, the East facing exterior girders experienced additional bowing due to temperature differences. At night, the girders all cooled down. At sunrise, the outboard face of the East facing girders rapidly heated up while their inboard faces remained cooler causing the temperature difference and additional on-site bowing. Since the West facing girders did not experience direct sunlight exposure until the afternoon, there was not a large temperature difference between the inboard and outboard faces.

Any horizontal bowing will impact deck forming operations. The contractor needs to be informed of the anticipated horizontal bowing caused by the asymmetric exterior girders. By indicating the anticipated horizontal bowing on the plans, the contractor can properly account for it with respect to their deck forming operations.

The precaster and contractor should carefully evaluate and accommodate the requirements for lateral stability (Ref. 4) in combination with horizontal bowing with respect to girder shipping, picking, placing, and temporary stability before deck & diaphragm placement.

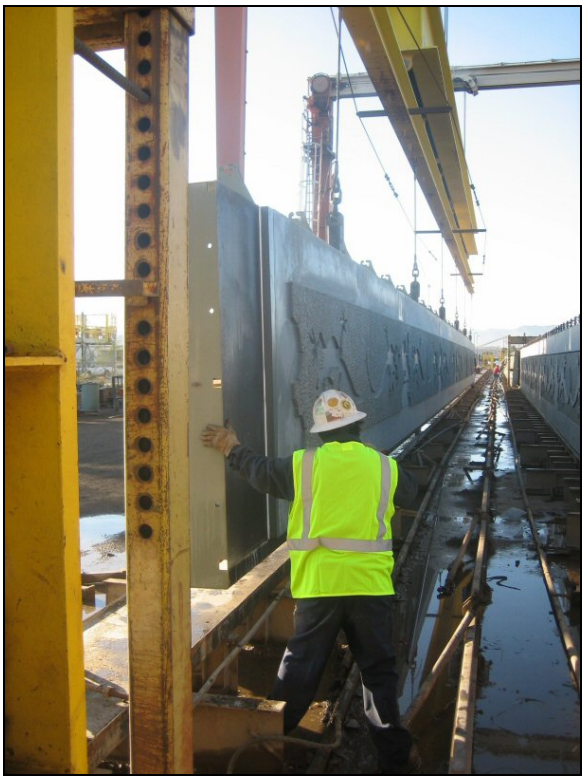

Fig. 8 Precaster's Custom Form for Outboard Face

CONCLUSIONS

The recently constructed Cotton Lane Bridge over the Gila River in Goodyear, Arizona utilized artistic form liners embedded in the outboard face of the prestressed exterior girders. Even with the complexities resulting from using an asymmetric section, this architectural enhancement still proved economically reasonable.

Design needs to account for the rotation of the principal axes relative to the vertical and horizontal axes. Prestress and self weight induce significant moments about the principal weak axis which causes bowing and additional stresses. Additional torsional and thus principal stresses arise from the offset of the shear center relative to the centroid of the section. Finally, the C-section has greater torsional rigidity due to its thicker web which influences live load and composite dead load distribution.

The use of end-braces and intermediate braces (diaphragms) will limit torsional stress to that caused only by self weight and prestressing. End-bracing diaphragms placed prior to the pouring of the deck concrete provide the added benefit of preventing end rotation, which will, in turn, minimize non-uniform pressure on the bearing pads under the fascia girders.

The asymmetric section required a modified prestressing strand pattern. Any horizontal eccentricity between prestressing center of gravity of prestressing and section centroid will cause horizontal camber and additional flexural stresses through weak axis bending.

Major construction considerations on the Cotton Lane project included increased horizontal bowing due to temperature differences, transporting & lifting the heavier section and using due diligence with respect to lateral stability.

The tremendous versatility offered by precast and prestressed concrete makes the creation of an asymmetric section with embedded form liner quite feasible and practical from both a design and construction perspective. While hanging aesthetic precast panels on standard exterior girders is also quite feasible & practical, embedding the aesthetics into the exterior girder section prior to prestressing has the added benefits of increased aesthetics (no vertical joints between the panels) and elimination of long-term maintenance on the panels.

REFERENCES

1. "Tolerance Manual for Precast and Prestressed Concrete Construction," MNL 135-00, Precast/Prestressed Concrete Institute, Chicago, IL, 2000.

2. Hambly, E.C., "Bridge Deck Behavior", John Wiley and Sons, Inc., New York, NY, 2nd Edition, 1991.

3. AASHTO 2004 LRFD Bridge Design Specifications, Customary U.S. Units, 3rd Edition, American Association of State Highway and Transportation Officials, Washington, D.C.

4. Mast, Robert F., "Lateral Stability of Long Prestressed Concrete Beams – Parts 1 & 2", PCI JOURNAL, V. 38, No. 1, January – February 1993